
BUCKMASTER'S TEXT-BOOK
EXPERIMENTAL PHYSICS

HE ELEMENTS

OF

STICS, LIGHT,

AND

HEAT.

BY

C. BUCKMASTER,

d Art Department, and Examiner in Chemistry and ysics to the Royal College of Preceptors.

ISED, CORRECTED, AND ENLARGED BY

CHARLES LEES,

Trade School, Northampton; Lecturer on Chemistry and cience at Clevedon College, Northampton, and at the Northampton Museum Science Classes.

FIFTH EDITION.

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J. C. BUCKMASTER,

Of the Science and Art Department, and Examiner in Chemistry and Physics to the Royal College of Preceptors.

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SYLLABUS

ISSUED BY THE SCIENCE AND ART DEPARTMENT.

ACOUSTICS, LIGHT, AND HEAT.

First Stage, or Elementary Course.

Questions will be confined to the following subjects :—

Acoustics.

The pupil ought to have a perfectly clear notion of the manner in which a *wave* is propagated.

He ought to know what is meant by the terms density and elasticity as applied to air and other bodies, and how heat and cold affect the density and elasticity of air.

He ought to be able to describe simple experiments to prove that air possesses both weight and elasticity. He ought to understand the law of Mariotte, the construction and use of the air-pump, and what occurs when a sounding body is placed in a space from which the air has been withdrawn.

He ought to be taught to see the play of elasticity in the propagation of a sonorous wave through air, and to have a clear mental image of the condensation and rarefaction which make up such a wave. He must, of course, be able to distinguish between the motion of a wave and the motion of the particles which at any moment form the wave.

He ought to know how the velocity of a wave is affected by a change of density, by a change of elasticity, or by a change of both.

He ought to know the velocity of sound in air of the freezing temperature, and also the amount of augmentation of velocity for every degree of the thermometer. The temperature of the air being given, he ought to be able to calculate the velocity of sound through it; and the velocity of sound being given, he ought to be able to calculate the temperature of the air.

No doubt or confusion must rest within his mind regarding the meaning of the terms *velocity*, *intensity*, and *amplitude*. He ought also to know the relation of the last two to each other.

He ought to know the laws of the reflection of sound by tubes and mirrors, and to be able to apply his knowledge to the explanation of echoes.

The law of inverse squares, as applied to sound, ought also to be explained to the pupil.

He ought to be able to figure mentally the propagation of a sound-wave through solids and liquids as clearly as through air; to know the velocity of sound through water, and to be able to infer from this the relation of the density of the liquid to its elasticity.

He ought to know how the velocity of sound through air has been determined, and to be well exercised in the calculation of distances by means of light and sound.

The pupil ought to know the physical difference between music and noise, and to be able to state the conditions on which the pitch and the intensity of musical sounds depend. He ought also to be able to describe various methods of producing musical sounds.

He ought to have clear ideas of the *length* of a wave, and of the *time* of a vibration. The length of a wave at a definite temperature being given, he ought to be able to calculate the time of a vibration; and the time of a vibration being given, he ought to be able to calculate the length of the wave.

He ought to be able to describe a method of determining from the pitch of a sound the number of vibrations per second which produce it.

He ought to know the structure of the drum of the ear, including the membranes that close it, and the bones that cross it.

He ought to know the laws of the vibration of strings, and to understand the use of sound-boards in stringed instruments.

He must have a clear idea of the formation of *nodes* upon a string, by the coalescence of direct and reflected waves.

He ought also to know the laws of vibration of columns of air in both stopped and open pipes. The exact condition of the air when the fundamental notes of each class of pipes is sounded, ought to be clearly present in the pupil's mind.

The cause of beats in music ought also to be explained to the pupil, and he ought to know the range of the human ear for musical sounds.

Light.

Before entering upon the subject of light, the teacher will have been careful to make his pupil perfectly familiar with the conception of waves of sound impinging upon the tympanic membrane, and the transmission of the tremor thus produced to the auditory nerve. He need not attempt to enter upon the details

of this transference to the nerve, but up to the tympanic membrane, and including it, the idea formed by the pupil of sound-waves and their action must be perfectly distinct. In all cases an image must exist corresponding to the teacher's words.

He must understand that the sensation of light is caused by something that hits the optic nerve. That this something, whatever it be, passes through the humours of the eye to reach the nerve behind. The conception of light known as the emission theory can afterwards be made clear to the pupil. According to this theory a ray of light would be a train of these particles.

That a ray of light proceeds in a straight line must be made known to the pupil. In connection with this point the inversion of objects by rays passing through small apertures must be explained.

The mode of determining the velocity of light by the eclipses of Jupiter's satellites must be explained to the pupil.

The law of inverse squares must be illustrated.

The cause of shadows and penumbræ must be explained.

The mode of determining the relative intensities of two lights by means of the "shadow test" must be explained.

The reflection of light from plane mirrors must be explained.

The pupil's attention must be drawn to the lateral inversion of objects by plane mirrors. He must know how the distance of an image behind a looking-glass is affected by a change of position of the glass in a direction perpendicular to its own planes.

The relation between the angular velocity of a reflected ray and the mirror that reflects it must be explained to the pupil. The multiplication of images by angular mirrors ought also to be explained, and also from it the appearance of the kaleidoscope rendered intelligible.

The formation of images by a concave spherical mirror ought to be explained to the pupil. The axis, principal focus, and centre of the mirror are to be pointed out. Beginning with a luminous point placed beyond the centre, and upon the axis, the successive positions of the image of this point during its motion along the axis from a great distance through the centre, through the principal focus, up to the surface of the mirror itself, must be determinable by the pupil. He will then be taught to determine the position of the images of points not placed on the axis. Objects of sensible dimensions, such as the pupil's own body, must then be substituted for points. (The teacher will avail himself of such simple apparatus as he can command in the

explanations here referred to; a silver spoon, if he possesses nothing better, will be useful.)

Real and *virtual foci* are to be defined.

The "aberration" of a large spherical mirror must be explained.

The refraction of light must be explained. By means of a simple geometrical construction the meaning of the "index of refraction" may be explained to the pupil without the introduction of the term "sine."

It must be clearly explained that an object looked at with a single eye appears more near the greater the divergence is of the rays which reach the eye from the various points of the object. From this it will be inferred that a lake or river, the bottom of which is visible, appears more shallow than it really is.

Various simple but instructive illustrations of the effects of refraction will occur to the teacher, such, for example, as the rendering of a coin visible by pouring water into a basin, and the apparent bending of a straight stick thrust obliquely into water.

The circumstances under which *total reflection* occurs must be clearly explained to the pupil.

The power and action of lenses must be explained; the teacher will define the *principal focus* of a lens. As in the case of a spherical mirror, he will begin with a luminous point, determining the position and character of its image, while it moves from a great distance up to the lens itself. He will pass from points to objects of sensible dimensions, and show how the position of the image of every point of such object may be determined.

Here also *real* and *virtual foci* are to be explained.

The explanation of the magic lantern is then to be introduced.

It would add much to the efficiency of the instruction if the teacher would illustrate the points here referred to by common spectacle lenses, provided he has nothing better.

The pupil in the first class is also in a condition to know what is meant by the spherical aberration of a lens.

He must understand the optical structure of the eye, be able to give a clear account of the conditions of distinct vision, and of the causes and remedies of long and short sight.

He ought to be acquainted with the fact that impressions persist upon the retina, and to know what is meant by irradiation.

He ought to know the principles of binocular vision, and to clearly comprehend how the impression of solidity is produced by the stereoscope.

He ought to be made acquainted with the composite character

of white light; and to be able to describe an experiment by which such light may be resolved into its coloured constituents.

He ought to understand the doctrine of colours as far as they are produced by absorption.

And he ought to understand the meaning of *chromatic aberration.*

Finally, it is to be stated to the pupil that according to our best knowledge the sensation of light is not produced by the impact of little particles darted out from luminous bodies; but that it is caused in a manner somewhat similar to the sensation of sound, namely, by the successive shocks of minute waves against the retina.

Heat.

The pupil should know the general effect of heat upon the volumes of bodies, and should be able to describe experiments illustrative of the expansion of solids by heat. He ought also to have an idea of the almost irresistible force of this expansion.

He ought to understand with perfect clearness what is meant by the *co-efficient of expansion,* linear, superficial, and cubical.

He ought to know by heart the co-efficients of expansion of gold, silver, platinum, iron, and glass; and the reason why it is possible to fuse platinum wire into glass without fracture on cooling.

He ought to know the principle of Breguet's metallic thermometer, and to be made acquainted with some of the precautions which changes of volume by heat and cold render necessary in the arts.

He ought to be able to describe and explain the gridiron pendulum.

He must be able to describe the construction and explain the use of the mercurial thermometer; the scales of Fahrenheit, Celsius, and Reaumur must be known to him, and he must be able to convert immediately the readings of any one of them into those of the others.

The dependence of the boiling point of water upon external pressure ought to be known, and the pupil must be able to give illustrations of this dependence.

He ought to know by heart the co-efficients of expansion ot water, alcohol, and mercury.

The pupil must be well acquainted with what is called the *maximum density* of water, to state at what temperature it occurs, and to point out its effects in nature.

He ought to be acquainted with the change of volume which

occurs when water passes from the liquid to the solid state, and to apply his knowledge to the bursting of water-pipes in frosty weather. He ought to be acquainted with the fact that expansion on solidification is not a property peculiar to water.

He ought to be able to describe experiments which shall illustrate the expansion of gases. The principle and action of the fire-balloon ought to be explained to the pupil.

The general principles of ventilation ought also to be known to him, and also the sun's action in the generation of winds. He ought to be able to explain the Trade Winds.

The constancy of the co-efficient of expansion of gases ought to be pointed out, with the small deviations from the general rule exhibited by carbonic and sulphurous acids. The chemical and physical character of these gases ought to be known to the pupil.

He ought to know the constitution, chemical and physical, of aqueous vapour, and how it is diffused in the atmosphere. He ought to know the meaning of the term *saturated* as applied to air charged with vapour.

The effect of expansion in chilling air ought to be known to the pupil, and also the condensation of the aqueous vapour diffused through the air in consequence of such a chill.

He ought to be able to see the application of this knowledge to the explanation of clouds and rain.

He ought to have a perfectly clear idea of what is meant by *specific heat* or *capacity for heat*, and to be able to describe the calorimeter of Lavoisier and Laplace. He ought to know by heart the specific heats of water, alcohol, mercury, iron, and lead; and to be made aware of the influence which the high specific heat of water exercises upon climate.

He ought also to be intimately acquainted with the facts covered by the term *latent heat.* Taking a block of ice at a temperature below the freezing point, he ought to be able to describe with perfect accuracy what occurs when the temperature of the substance is raised until it liquefies, boils, and is converted into vapour.

The latent heat of water, as expressed on the Fahrenheit and centigrade scales, ought to be in the pupil's memory.

The cold of evaporation and its effects in freezing water in the cryophorus ought to be known to the pupil.

He ought to be exercised in calculations on the changes of temperature due to the mixture of steam and water in various proportions.

The pupil ought to know what is meant by the *conduction* of heat, and must be able clearly to distinguish it from the distribu-

tion of heat by *convection.* He ought to know by heart the numbers expressing the relative conductivity of gold, silver, copper, iron, and lead.

He ought to be acquainted with the low power of conduction of organic substances; to know the effect of mechanical texture on the transmission of heat, and to explain the function of clothes in preserving the body from cold.

He ought to be acquainted with the character and phenomena of combustion; to be able to explain the chemical actions which occur in the combustion of coal and of ordinary gas, and to explain the manner in which a candle flame receives its supply of combustible matter.

The combustion of the diamond and Newton's prediction regarding it ought to be known to the pupil. That animal heat is due to slow combustion ought also to be made known.

The structure of an ordinary gas flame ought to be pointed out, and the cause of the difference between this flame and that of a Bunsen's burner explained.

The pupil must be acquainted with the general phenomena of *radiant heat.* The similarity between the phenomena of radiant heat and those of light, as regards reflection and refraction, ought to be known to the pupil.

The different powers possessed by different substances to radiate heat ought to be pointed out, and this knowledge ought to be applied in explaining the striking fact that the cooling of a vessel may, under certain circumstances, be hastened by surrounding it with flannel.

The reciprocity of radiation and absorption ought to be known to the pupil.

He ought also to know what is meant by the term *diathermancy,* and to be able to point out how this property is manifested by different bodies.

SECOND STAGE, OR ADVANCED COURSE.

Questions may be set in all subjects enumerated under the Elementary Stage, and in addition on the following topics:—

Acoustics.

The second course in acoustics includes an intimate knowledge of all the subjects mentioned in the first. In addition to this a knowledge of the following subjects will be required:—

The augmentation of the velocity of propagation of a wave of sound through air by the condensation and rarefaction of the sound-wave itself.

Harmonic tones, their generation and their function in music.
The laws which regulate the transverse vibrations of rods.
The vibrations possible to a tuning-fork, a disc, and a bell.
The formation of Chladni's figures.

The laws which regulate the longitudinal vibrations of strings and rods. By a comparison of the notes emitted by a rod and a column of air the pupil ought to be able to determine the relative velocities of sound through both substances.

The conditions and cause of resonance ought to be known to the pupil.

He ought also to know how sounds are produced by the vocal organs of man, and to see clearly the similarity between such sounds and those of the syren. As a case of the same kind, the construction and explanation of the Æolian harp ought also to be known to the pupil.

He ought to be well acquainted with the principles of interference as applied to sound.

He ought to be acquainted with the principles of harmony, to know the ratios of the vibrations corresponding to the notes of the gamut, to be able to give a clear account of the bearing of interference upon the question of consonance or dissonance, and to explain why those ratios which are represented by small whole numbers correspond to the most perfect harmony.

Light.

The candidate in the second course must be intimately acquainted with all the subjects mentioned in the first.

He must be able to apply his knowledge of total reflection to the explanation of the mirage of the desert.

He must be able to describe experiments by which white light may be produced by the admixture of its constituents.

He must know what is meant by *achromatism.*

He must be able to give a clear description of the undulatory theory, and to state how the colours of the spectrum are accounted for by that theory.

He must be able to define a ray of light in accordance with the undulatory theory.

He must be able to show how the reflection and refraction of light occur according to the undulatory theory.

He must be able to describe the appearances presented when incandescent metallic vapours are analyzed by the prism. Especially must he be able to state what occurs when a sodium flame is thus analyzed.

He must also be able to state what occurs when white light is transmitted through a sodium flame, and he must be able to describe an experiment which shall render manifest what occurs.

He must be able to state generally the relation that subsists between radiation and absorption by gases and vapours.

The lines of Frauenhofer must be known to the pupil, and from this knowledge, in conjunction with the knowledge demanded by the foregoing paragraphs, he must be able to infer the probable constitution of the sun.

The pupil ought also to know the principles of interference as applied to light.

He ought to be able, in accordance with these principles, to account for the colours of thin plates and of striated surfaces.

The general principles of diffraction ought to be known to the pupil.

He ought to know what is meant by plane polarized light; to describe the act of polarization in the language of the undulatory theory.

He ought to know what occurs when a beam of light is transmitted through a crystal of Iceland spar, and to describe the state of the emergent light as regards polarization.

He ought to be able to describe the effects observed when light is transmitted through two plates of tourmaline cut parallel to the axis of the crystal.

He ought to be able to describe some form of the polariscope, and to state and explain by the principles of interference what occurs when a thin plate of selenite is placed between the polarizer and analyzer.

Heat.

The candidate in the second course must be intimately acquainted with all the subjects introduced into the first.

He ought to be able to give a clear statement of the *mechanical theory* of heat as distinguished from the *material theory.*

He must know what is meant by the "mechanical equivalent of heat," and how it has been determined.

He must know what is meant by specific heat at constant volume and at constant pressure, and have in his memory the numerical ratio of the two specific heats.

He ought to be able not only to explain the meaning of the difference between the two specific heats in accordance with the mechanical theory, but also to show how from this ratio the mechanical equivalent of heat may be determined.

Given the weight and velocity of a moving body, he ought to

be able to calculate the amount of heat generated by the stoppage of the motion.

He ought to be able to apply the conceptions of the mechanical theory to the phenomena of combustion.

He ought also to be able to show the bearing of the theory upon the phenomena of specific and latent heat.

EXAMINATION FOR HONOURS.

The candidate for honours must be intimately acquainted with the foregoing two courses. He must also show himself practically acquainted with the apparatus employed in acoustics, light, and heat.

PREFACE TO THE FIFTH EDITION.

SOME years ago I was encouraged to write a small Text-Book for the instruction of a class in Natural Philosophy. When the subject of scientific instruction was taken up by the Science and Art Department I endeavoured to make my books useful in facilitating the attainment of sound elementary knowledge in science. My official work in connection with the Department, now extending over a period of fifteen years, has prevented my giving that attention to a revision of the books which from time to time appeared necessary. I felt the best thing I could do was to secure the co-operation and help of the most experienced and successful teachers of the sciences to which the books relate, so as to make them worthy the object for which they have been prepared.

J. C. BUCKMASTER.

St. John's Hill, Wandsworth, S. W.,
January, 1871.

THE ELEMENTS

OF

ACOUSTICS, LIGHT, AND HEAT.

ACOUSTICS.

SOUND is caused by the mechanical vibrations of an elastic body, which are transmitted by undulations through the atmosphere or some other medium to the ear. The vibratory body is said to be sonorous. If a glass tumbler be gently struck with any hard body, a tremulous agitation is communicated to the entire mass. The surrounding air is thrown into corresponding waves, which strike upon the tympanum or drum of the ear, producing a vibratory motion in that delicate membrane. This motion is again communicated to the brain by the auditory nerve, giving the sensation of hearing. We hear, then, by means analogous to those by which we see; for in a similar manner the waves of light strike the eye, and are conveyed by the optic nerve to the brain. Suppose a stretched cord, represented by the line A B C, *Fig.* 1, to be drawn aside to D; in returning to its original position it does so with a momentum which carries it past the line A B C to A E C, from which it returns again nearly to A D C, and so backward and forward, until, after a number of oscillations, it comes to a state of

rest. The space through which the cord oscillates, or the amplitude of the oscillations, diminishes, but the

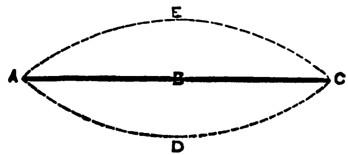


Fig. 1.

time required for a small oscillation is the same as that required for a large one.

Amplitude of Vibration in Air.—In like manner during the passage of the sound-wave through the air, each particle of air oscillates to and fro, giving motion to neighbouring particles in all directions, and these again in their turn impart motion to the surrounding air; just as, in a large crowd of people, we see the agitation of the centre gradually spread to the outer circles by the motion passing from one person to another. Although sound may be heard at great distances, yet each particle of air makes only a short journey to and fro, called its amplitude of vibration.

Elasticity and Density.—The velocity of sound depends upon the elasticity of the air, and also upon its density or weight. The elasticity of air is measured by the pressure which it can sustain. At the sea-level this pressure is equal to that of a column of mercury 30 inches in height; on a high mountain the pressure is less in proportion to the height.* In this case the air would be said to have less elasticity on the top of

* For a rise of 590 feet the mercury column falls one inch. (*See Exercise I.*)

the mountain than at the sea-level. If air be heated in a closed vessel its elasticity increases, whilst the weight remains the same; the velocity of sound passing through such air is increased. If the air of the open atmosphere be heated it expands, its elasticity remains the same, while the weight is lessened, and, as before, the velocity is increased. The velocity of sound in a warm temperature is therefore greater than in a cold one. Now we see the reason for saying that at a freezing temperature the velocity of sound is 1,090 feet per second, and the increase for rise in temperature is about 2 feet for every degree centigrade. It is common to take the velocity of sound at 1,120 feet per second, the temperature being at 62° F. When this is the case, a rise of 13 inches for every degree Fahrenheit must be allowed.

From this it is easy to calculate the velocity of sound when the temperature is given, and with a given velocity to ascertain the temperature of the air. (*See Exercise I.*)

From the known velocity of sound, it is not difficult to calculate the distance between two places. Let a pistol be fired at the distant place, and note the time carefully between seeing the flash and hearing the report. Let this interval of time be expressed in seconds and multiplied by $(1{,}090 + 2\,t)$. This will give the distance in feet, and the value t will be given by the centigrade thermometer. In this calculation the direction and velocity of the wind are neglected. (*See Exercise I.*)

It must be borne in mind that it is neither the elasticity nor the density alone that affects velocity, but the two together, according to the relation which exists between them, and in accordance with the following *laws*:—

1. *The velocity of sound is proportional to the square root of the elasticity of the medium.*
2. *The velocity is inversely proportional to the square root of the density.*

Thus, in the example of the air heated in a closed vessel, if the elasticity be increased four times, the velocity will be doubled. The velocity would also be doubled if the density in the second case were reduced to ¼; so that if the two vary alike they act upon the velocity in contrary directions, and exactly neutralize each other. The law of Mariotte and Boyle shows that they do thus neutralize each other if the temperature be the same in the substances under experiment. The law may be demonstrated by an instrument known as Mariotte's tube (*Fig.* 2). It consists of a long glass tube, bent at the end and open at the top of the long limb only; both the limbs are graduated. A small quantity of mercury is put into the tube, so as to mark off a certain volume of air which is now under ordinary atmospheric pressure. Reduce the volume of the air one-half by adding more mercury, and it will be found that the mercurial column is exactly the height of the barometer column of mercury; that is, you have doubled the pressure to obtain half the volume. Other similar experiments will still further demonstrate the law that, "*temperature remaining the same, the volume of a gas is inversely as the pressure.*"

Fig. 2.

A beautiful illustration of the law as applied to density, elasticity being the same, is shown in the velocities of sound in the gases hydrogen and oxygen :—

	Velocity.	Atomic weights.
H . .	4,164 ft. per sec. .	1
O . .	1,040 ft. ,, .	16

Hence the density is as 1 to 16, therefore velocity is $\frac{1}{4}$ in the case of oxygen against 1 in hydrogen.

The Air-pump.—Perhaps the instrument known as Tate's is at the same time the simplest and most efficient, *Fig.* 3. It consists of a cylinder and double

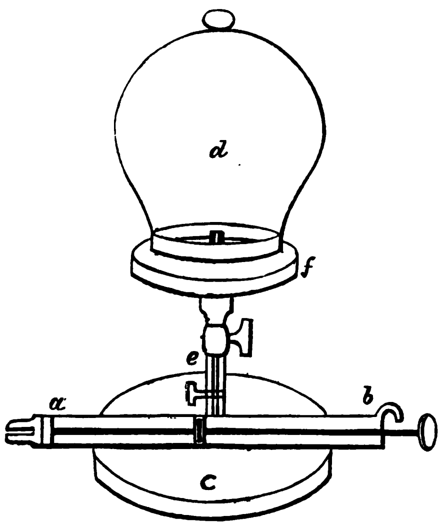


Fig. 3.

piston, *a b*, in the form of a syringe, placed horizontally on a wooden foot *c*. At each end the air is expelled as it passes from the receiver *d* down the tube *e*. In this tube stopcocks are placed to pre-

serve the vacuum when obtained, or to readmit the air. The syringe at the base may be used for compressing air if the vessel to be filled is attached to the end *a*.

EXPERIMENTS.—Remove the receiver, and attach by a screw, which enters the plate *f*, a globe provided with a stopcock; exhaust the air, then carefully weigh the globe; readmit the air, and weigh again. The difference between the two weights will show the weight of the volume of air contained by the globe.

Again close the end *a* of the syringe, cut off communication with the receiver. Force the air in the syringe to the end *a*, remove the pressing force, and it will be found that the piston will return to its former position with a force equal to the pressure formerly applied. This demonstrates the elasticity of the air:—compress a bladder containing any gas, remove the force, and it will return to its former volume. Many other simple experiments to demonstrate this elasticity of gases will occur to the thoughtful reader.

Again: that air is necessary for the passage of sound is easily proved by the experiment of enclosing a bell within the receiver of an air-pump. As the exhaustion of the air proceeds, the sound of the bell grows fainter and fainter, until at last it nearly dies away. The hammer is seen to strike the bell, but there is no sound, because there is no medium to convey these undulations to the ear. The experiment is never quite successful, owing to the impossibility of obtaining a perfect vacuum, and insulating the bell from the metallic plate of the air-pump. Sound is also transmitted through water, wood, metals, &c., but with different velocities. Through water it moves more rapidly than through air, and with increased velocity as the temperature of the water increases. At

15° centigrade sound travels through river water at the rate of 4,714 feet per second; at 60° centigrade at the rate of 5,657 feet per second. If a pistol be fired over a stream of water where fishes can be seen, the agitation among them shows they have heard the report; and even talking on the bank will disturb them. The sound of a bell rung under water may be heard at a long distance by a person diving.

In fir wood the velocity of sound is 15,000 feet per second. The scratch of a pin may be heard from one end of a piece of timber to the other, and the more readily when in the direction of the grain of the wood.* The principle of solids being able to transmit sounds has been applied to the construction of the STETHOSCOPE, which consists of a hollow cylinder of wood like a small trumpet. The wide mouth is applied to the chest, and the other is held to the ear. The medical man is thus enabled to hear distinctly the action of the organs of respiration, and can form an opinion as to their healthy action or otherwise.

Condensation and Rarefaction.—Possessing elasticity, the air suffers rarefaction as well as condensation on the passage of a sound-wave. Suppose a long pipe to be filled with india-rubber balls, and that motion is given to the first ball at one end, then we shall readily understand that as the motion travels there will be a motion of compression whereby the balls will be successively brought near each other, and a rebound by which there will be a motion of separation passing along the whole length. The compres-

* Here note that whilst density in solids or liquids is certainly greater than in air, and hence the velocity might be expected to be less, and, indeed, is generally thought to be, yet, taking the elasticity into consideration, which in wood, &c., is so much greater than in air, the velocity is immensely increased.

sion represents the condensation of the air particles, and the rebound and consequent separation the rarefaction. It will be convenient to speak of this with a view also to this fact, that the compression produces a rising up of the particles, which will represent the rise of the undulation, and that the rarefaction has the opposite effect, and produces what we may call a depression. Thus we have the true wave formed, which in this country is always considered to consist of a condensation and rarefaction together. In France it is usual to speak of one sound-wave as consisting of two waves, the rise being one and the fall the other.

Knowing the number of vibrations per second, it is easy to determine the wave-length. Divide the distance passed over by the sound in a second by the number of vibrations executed in that time, and the quotient will be the length of the wave. (*For exercises on the wave-length and the time of a vibration see Exercise II.*)

Intensity of sound, which is usually understood as its loudness, depends entirely upon the amplitude of vibration, and therefore on the power of the exciting cause. It is, moreover, proportional to the square of the amplitude; hence, if the particles of air in one sound-wave swing twice as widely as the particles in another, the intensity of the sound in the one case is four times what it is in the other. When an explosion takes place, it is manifest that the further the sound-waves proceed the more their motion will be enfeebled; the intensity of the sound will be diminished as the square of the distance increases. At a double distance from a sounding point the intensity of the sound is one-fourth; at a treble distance it is one-ninth, and so on.

If the sound-waves, instead of being permitted to

spread abroad, and thus become weaker, be confined in a tube possessing a smooth interior surface, the waves may be conveyed to great distances without much diminution of intensity. In Speaking Trumpets, the undulations, instead of diverging and being scattered in the surrounding atmosphere, are carried forward in straight lines, and thus their intensity is in a great measure preserved. The same principle is employed in Speaking Tubes, used for communicating between different apartments in the same building. In the Hearing Trumpet, which is intended to assist persons hard of hearing, the principle is reversed; the sound-waves enter at the larger end, and are so condensed and concentrated as to give a much greater intensity to the sound than an ordinary undulation would give.

The power of the atmosphere to transmit sound varies according to its humidity, density, and other circumstances. Anything which disturbs the condition of the atmosphere interferes with the transmission of sound. When the wind blows from the hearer towards the sounding body, the sound, which would be distinctly audible in a calm, often ceases to be heard. The undulations of sound-waves are also obstructed by the falling of rain or snow. In cold clear weather sound is transmitted to a greater distance than in warm weather, because the density of the atmosphere is increased by cold and diminished by heat. At night the air is less liable to variations of temperature and the noises of business. Many sounds are distinctly perceptible on a still, calm evening, which would be completely destroyed in the daytime before they reach the ear. On the top of high mountains, where the air is greatly rarefied, the human voice can be heard only for a short distance, and the report of a pistol sounds like a penny cracker; but in a diving-bell, where the

air is greatly compressed, a gentle whisper is almost as loud as a shout in the open air.

The velocity of sound in air has not been determined without innumerable and most exact experiments. The site of the trial requires careful measurement, the temperature of the air must be exactly ascertained and allowed for, the force and direction of the wind must be taken into calculation, and the moisture of the atmosphere must be considered. The velocity of light, being so immense, may be ignored for such distances as are available for acoustical experiment. A pistol is fired, the observer at a known distance sees the flash, and must carefully note the time between this and the moment when the sound arrives. This time, into the distance, will of course give the velocity. (*For calculation of distance by means of light and sound the student is referred to Exercise II.*)

The condensation of the sound-wave increases the temperature, whilst in the rarefied portion of the wave the air is chilled. Newton calculated the velocity of sound, allowing for the increase of elasticity because of increased density, but neglecting the increase of the same for increased temperature. He gave the velocity of air at 916 feet per second at 0° C., which is about 1-6th below the true velocity. Laplace corrected his calculation, and discovered the omission which accounted for the discrepancy.

Musical Sounds.—The regular and uniform vibrations of sonorous bodies, which are perfectly periodic and sufficiently rapid, produce musical sounds. When the succession of waves is irregular and confused, or results from a single impulse communicated irregularly to the ear, the effect produced on that organ is called Noise.

In all musical sounds the vibrations of the sonorous body must be exactly alike in duration, *i. e.*, must recur after equal intervals of time: such vibrations are called *isochronal.*

The pitch depends entirely upon the rapidity of the vibrations. Very rapid vibrations are said to produce acute or sharp sounds, whilst those which arise from very slow vibrations are said to be grave. These terms, high or low, acute or grave, are only relative. One sound may be acute with reference to a second sound, while it may be grave with reference to a third. A sound produced by 160 vibrations in a second must be acute or high with reference to one of 80 vibrations, and grave with reference to one of 320 vibrations. A combination of these acute and grave sounds according to harmony constitutes music.

Sixteen vibrations per second produce the lowest and 32,000 the highest sounds of which the human ear can judge. If we take 1,120 feet as the velocity of sound, we find for the length of the undulations corresponding to the gravest sounds, 70 feet, and to the acute sounds 2-5ths of an inch.

The limit of sounds for music is much less, especially in singing. Savart gives for the gravest sounds of the male voice, 190 vibrations per second, and for the female voice, 572. For the most acute sounds of the male voice he gives 678 vibrations per second, and for the female voice, 1,606.

Although authorities differ with regard to the power of hearing, they all agree in ascribing to it a limit. In some animals the power may commence where it ceases with us, and they may have the faculty of hearing sounds of a much higher pitch than we actually know, from experience, to exist.

To ascertain the particular pitch of any sound, we

must have some means of measuring the particular lengths of the different waves by which the sound is made sensible to the ear. These are furnished by an instrument called—

The Syren, *Fig.* 4.—This instrument consists of a disc of Bristol board, 12 inches in diameter, perforated

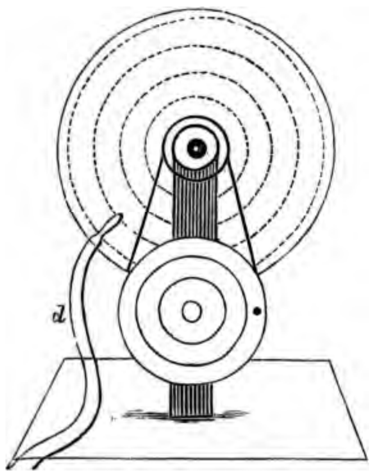


Fig. 4.

at equal intervals in circles parallel with the circumference. The disc is attached to a multiplying wheel, and caused to rotate rapidly. Immediately over a circle of holes is placed a flexible tube, *d*, the other end of which is applied to the mouth. If the tube be over one of the holes, the air from the mouth will pass through; but by causing the disc to turn rapidly the

stream of air is broken into a quick recurrence of puffs, which produce a musical note; the puffs of air are vibrations, the same as those produced by strings or reeds. The more rapid the motion, the higher the pitch of the note. With this instrument any musical note can be imitated, and the number of vibrations necessary to produce the particular pitch of that note may be easily ascertained. Suppose, for instance, we require to know the number of vibrations made per second by a tuning-fork. Cause the disc to revolve so that the sound of the fork is reproduced; note the number of revolutions made per second. We will suppose this number to be 24; then count the number of holes in the circumference of the disc, say 16. Then the number of puffs of the instrument or vibrations of the tuning-fork equals $24 \times 16 = 384$. For simplicity of illustration a low number of perforations has been taken. Mr. Ladd's apparatus contains 1,682 perforations, and by it 15 notes and 7 chords are produced. Connected with the axis of rotation of the disc is a stop register, to indicate the number of revolutions, and a stop watch is sometimes attached, to indicate the time.

The following table is taken from experimental researches on this subject by M. Byot:—

Number of Vibrations in one Second.	Length of Resulting Wave in Feet.
1	1,091·34
2	545·67
4	272·83
32	32·10
64	17·05
128	8·52
256	4·26
512	2·13

Number of Vibrations in one Second.	Length of Resulting Wave in Feet.
1,024	1·06
2,048	0·53
4,096	0·26
8,192	0·13

Another instrument, *Fig.* 5, is sometimes employed to determine the number of vibrations. A A is a solid framework of wood, which supports a large wheel, W; from this wheel, motion is communicated to a cog-wheel, W′, by means of a band, *b*; the teeth of this cog-wheel strike against a piece of card, C; the successive shocks given to the card are imparted to the atmosphere. When the velocity of the cog-wheel is small, a succession of gentle taps is heard, but as the velocity increases these taps appear to unite to produce a continuous note, the pitch of which is determined by the rapidity with which the card is struck. If we know the number of revolutions made by the

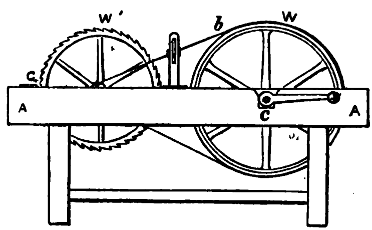


Fig. 5.

wheel in a second, and also the number of teeth in the wheel, we can easily determine the number of strokes given to the card in a second of time. By

this instrument a note of the same pitch can be produced as that of a gnat, a bee, or a beetle, when it flaps its wings, and the number of these per second can be inferred with the greatest accuracy.

Interference of Sound.—Beats.—When two waves of water meet or overtake each other so as to cause the alternate condensations and rarefactions to coincide, the rise and fall of the water-wave will in each case be greater than the rise or fall of a single wave; but if the depression of one wave coincide with the increase in altitude of the other, there will be either a partial or complete destruction of the two waves. This is precisely what takes place with sonorous waves. The elevation of one sound-wave corresponding more or less with the depression of the other gives as an effect the partial or complete destruction of the sound. This is called interference of sound. If we place on a wind-chest two organ pipes of the same pitch, they will so influence each other that the wind at the moment of leaving one pipe will enter the other; the depression of one wave thus produced will coincide with the elevation of the other, and the sound of both will be completely destroyed. The sound from a vibrating tuning-fork is much reduced by the interference of the sound-waves from the opposite prongs; in some positions it is entirely destroyed. Place a vibrating fork near the ear, and it will be noticed that when a corner of the prongs is brought opposite the ear the sound is completely lost.

If two musical sounds of nearly the same pitch be sounded together the effect will be, as it were, a series of shocks of sound separated by a corresponding series of pauses; they are caused by the alternate coincidence and interference of the two systems of sonorous waves. The shocks of sound may be called

beats, and the rate at which they succeed each other is equal to the difference between the two rates of vibration. Coincidence or interference will take place as the distance between the two sources of vibration amounts to an even or odd number of semi-undulations. The ringing of a large hand-bell will illustrate this part of our subject well. There is a regular rise and fall—a full sonorous tone, followed by a lull, and this with the greatest regularity. The same may be noticed by an attentive ear in the tones from a church bell, and, indeed, from any musical instrument.

Musical Concord.—Two musical notes sounded together may be either pleasant or unpleasant to the ear; they may be either harmonious or dissonant. The most harmonious combination is when two notes of exactly the same pitch are sounded together; we have then perfect unison. Here the vibrations of the respective notes are in the ratio of 1 : 1. This rather intricate part of our subject will be understood from the following table. The experimenter uses two tuning-forks on each occasion:—

No. of Vibrations.	Note.	Ratio.	Character.
256 256	Perfect unison	1 : 1	Tone pure
256 512	Octave	1 : 2	,, nearly pure
256 384	Fifth	2 : 3	128 beats, slightly impure
384 512	Fourth	3 : 4	128 beats

Any higher proportionate numbers than these give

a lower number of beats, and this introduces dissonance.

The following important laws may be here noted :— 1. The smaller the numbers which express the relative rates of vibration of two notes, the more agreeably do they strike the ear when they are sounded together. Simplicity, so to speak, is the law of harmony. 2. Dissonance is at a maximum when the *beats* number 33 per second; it lessens gradually, and disappears when the beats amount to 132 per second.

To illustrate what has been said, attach points to the prongs of several tuning-forks of different pitch, cause them to vibrate, and, whilst doing so, allow the points slightly to touch a piece of smoked glass, draw the forks gently along, and a series of sinuous lines will be formed; by counting the number of indentations in a given length the pitch of the forks may be ascertained. Thus, supposing three forks sounding a fundamental note, a fifth, and an octave to be thus combined, and that an inch of the line formed by the fundamental fork contains sixteen undulations, an inch of that produced by the fork which sounds the fifth will contain twenty-four, while the fork that sounds the octave will produce thirty-two undulations. These numbers are in the ratio of 2 : 3 : 4, which, as we have already learned, express a note, its fifth, and its octave.

A Musical Scale is a regular gradation of sounds occurring in the natural order of tones and semitones in groups of seven; each group constitutes a Gamut or Diatonic scale. These notes are distinguished by letters and names :—

Do, Re, Mi, Fa, Sol, La, Si, Do^1,
or C, D, E, F, G, A, B, C^1.

The first six of these names are the first syllables of

the first six verses of the hymn that is chanted at Rome on the feast of St. John.

These notes may also be distinguished by numbers, which indicate the relative lengths of the strings and the relative numbers of vibrations necessary to produce the notes. If the length of the string producing the primary key-note be 32 inches, the length of the strings to produce the tones in the entire scale are—

Do, Re, Mi, Fa, Sol, La, Si, Do^1.
32, 30, 27, 24, 21, 20, 18, 16.

Whatever be the number of vibrations per second necessary to produce the first note, Do, if we represent it by unity, then the numbers necessary to produce the other seven notes of the octave will be—

Do, Re, Mi, Fa, Sol, La, Si, Do^1.
$1, \frac{9}{8}, \frac{5}{4}, \frac{4}{3}, \frac{3}{2}, \frac{5}{3}, \frac{15}{8}, 2.$

And to whatever length this musical scale be extended, it will still be found a repetition of similar octaves. A column of air vibrating in a pipe obeys the same general law. The shorter the pipe, the higher the note. If the same note be produced on any musical instrument, that note is due to the same number of vibrations per second. The note of a piano produced by a string which vibrates 256 times in a second, is also produced by a flute in which a column of air vibrates the same number of times in a second.

Vibrating Strings.—A stretched string executes its vibrations in equal times, consequently it produces musical notes. The string itself, being very slight, imparts but a small amount of motion to the air. It is connected with a surface more or less large, generally called a sound-board, which takes up the vibrations and transmits them to the air, as in the piano or

violin. The force by which a string is stretched is called the tension of the string.

The number of vibrations made by a string vary according to the following rules :—

1. The number of vibrations, or pitch of the note, increases with the square root of the tension. If two strings of the same length, material, or diameter be stretched by different weights, the rates of vibration are proportional to the square root of the stretching force. If one string be stretched by a weight of 9 lbs., and the other by a weight of 16 lbs., the rates of vibration of these strings will be as the square root of 9 is to the square root of 16, or as 3 : 4. The key-pins of musical instruments are arranged to act as weights in giving tension to the string.

2. The number of vibrations is inversely proportional to the length of the string.

That is, with the same tension, diameter, and material, a string 2 ft. long will vibrate twice as often as one 4 ft. long. Violin players vary the lengths of the vibrating parts of the strings of that instrument, by pressure of the fingers. Higher tones are in this manner produced.

3. The number of vibrations is in the inverse proportion of the diameter of the string.

Other conditions being the same, a string one inch in diameter will vibrate twice as often as a string two inches in diameter.

The strings for the lower notes of a piano are not only thick, but they are wrapped with wire to increase their diameter.

4. The pitch of a note is inversely proportional to the square root of the density of the substance composing the string.

With tension, length, and diameter the same, let the

number 4 represent the density or specific gravity of the substance of one string, and 16 that of another; then the vibrations will be as 4 : 2—that is, the first string will vibrate twice as rapidly as the second.

From these laws we obtain the following formula:—

Let n be the number of vibrations per second, l the length of string, s the stretching force, d the diameter of the string:—

$$n = a \times \frac{\sqrt{s}}{l\,d}$$

a is the number depending on the quality of the material of the string, and will vary if two different strings be compared, and it follows that $a = \frac{n\,l\,d}{\sqrt{s}}$, by which the value of a is determined.

An instrument called a monochord may be used for illustration. For variation in length of string there is a moveable bridge D, *Fig.* 6. Other strings of varying thickness may be inserted for experiments with regard to diameters. For pressure the weight F may be removed and any other put in its place. For difference of material in class experiments arbitrary numbers may be chosen. (*Calculations will be found in Exercise III.*)

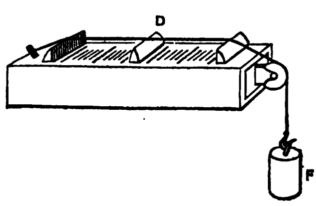


Fig. 6.

Harmonic Tones, their Generation and Function.—Let a rope or piece of india-rubber tubing be fixed at one end, and a jerk be given at the other end with the hand, the protuberance raised proceeds along the rope to the end and returns. A number of jerks given in rapid succession will produce a series of waves, which will be met by a return series; the direct and reflected waves so meet as in some parts to combine their forces, in others partially to neutralise each other, and in others, again, completely to destroy each other; this divides the rope into a number of vibrating parts, called ventral segments; and points at rest, named nodes, or nodal points. It is the same with a musical string or a vibrating column of air. The same string can vibrate as a whole, or it can divide itself into any number of vibrating parts, all of equal lengths. This division of a musical string may be rendered visible to the eye by placing little riders of paper on the string in the instrument called a monochord, before alluded to, at the ventral segments and at the nodes. When the string is sounded, the riders on the ventral segments are thrown off while those at the nodes are undisturbed. The nodes may be produced by placing small obstructions on the wire, pressing with the finger, for example, at the middle or at one-third from one end, or one-fourth, &c.

The notes corresponding to the division of a string into its aliquot parts are called the harmonics of the string. In the Æolian harp a string emits its harmonic sounds, in addition to the fundamental or chief tone, being divided into vibrating segments by a current of air. These smaller vibrations are superposed upon the larger and mingle with it. The addition of these higher notes, which may be called overtones to the

fundamental tone, determines the timbre or quality ot the sound. When a bell is sounded the attentive ear can distinguish the harmonics produced by the vibrating segments as well as the fundamental note produced by the whole.

Chladni's Figures.—The oscillations of sonorous bodies are too rapid to be either seen or counted; but by a simple experiment we can make them manifest to the eye. Sprinkle some fine dry sand on a plate of thin metal or glass, holding the plate with a pair of pincers, or better, with a holder provided with a screw *b* to fix it firmly to the edge of a table, and another screw *c* to grasp the plates firmly. (*Fig.* 7.) Then draw a violin bow over one of its edges; the particles of sand will be seen to dance up and down, and finally arrange themselves in curious figures. Now this motion is due to the vibrations of the plate. The lines where the sand collects and rests are the nodal lines, or lines of rest, whilst the vibrating segments of the plate have the sand completely removed from them by the vibratory motion.

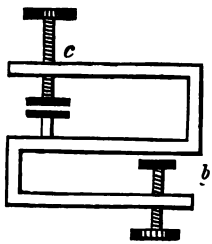


Fig. 7.

If we strike a tuning-fork, and then touch the surface of some mercury, the undulations or waves are distinctly visible.

By experiments made by Chladni, the following laws were detected:—

1. Any particular sound always produces the same figure, the plate being held in the same position. If the sound be changed, the figure disappears at once and a new one is formed.

2. The gravest sound is accompanied by the sim-

plest figure, and the more acute the sound, the more complex the figure—that is, the more nodal lines and points will be produced on the plate. The nodal lines and points are the fixed lines and points at which the sonorous body remains still, while the vibratory parts are in motion. In the last-mentioned experiment, if the plate of metal or glass be square, on agitation, so as to obtain the lowest note, there will be produced an arrangement of the sand particles into four smaller squares, giving two lines of sand crossing each other at the centre and parallel to the sides of the plate (*Fig.* 8, *a*). The next lowest note gives an arrangement as in *Fig.* 8, *b*.

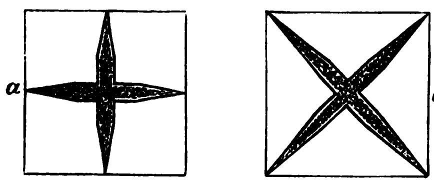


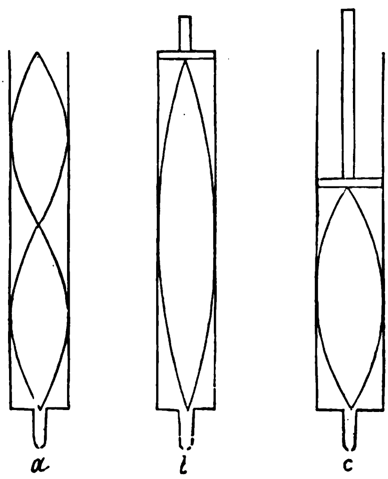
Fig. 8.

Round plates may also be divided into zones, the nodal lines forming circles; or into vibratory sectors, the nodal lines coinciding with the diameters. Most complex and beautiful figures are in this manner produced by the higher notes.

The experiments of Savart show that the molecular motions of one body may be communicated to another if there exist any intervening medium, and the more perfect the medium the more perfect the communication.

Moisten a thin membrane, stretch it over the top of a tumbler, and secure it with a piece of twine; place

it in a horizontal position, and, when dry, strew fine sand over the surface; hold a glass plate, covered with fine dry sand, horizontally over the membrane, and set it in vibration by drawing a violin bow over one of its edges, so as to produce the acoustic figures; these figures will be immediately imitated and produced in the sand on the membrane. If the plate be *inclined to the plane of the membrane*, the figures will change, although the vibrations will remain the same.



a b c

Fig. 9.

Organ Pipes.—In organ pipes a column of air is the vibrating body. Such pipes are either stopped or open. An open organ pipe yields a note an octave

higher than that of a closed pipe of the same length: this necessarily follows from the different modes of vibration. When a stopped organ pipe sounds its deepest note, the column of air is undivided, but when the deepest note of an open pipe is sounded, the column is divided by a node at its centre: the open pipe forms, as it were, two stopped pipes with a common base at the centre. In *Fig.* 9 we have a representation of the wave formation in the two classes of pipes; *a*, open pipe; *b*, stopped pipe; *c* represents a useful pipe for experiment: one side is of glass, and the piston or stopper is moveable. Any sound can be obtained, and position of the stopper be noticed. The order of the tones of an open pipe is that of the even numbers, 2, 4, 6, 8, &c. A closed pipe divides itself into vibratory segments, whose rates of vibration are in the proportion of the numbers 1, 3, 5, 7, &c. The length of a stopped pipe is one-fourth that of the sonorous wave which it produces, while the length of an open pipe is one-half of its sonorous wave.

In the harmonium and accordion the vibrations are produced by metallic tongues called reeds; these are also sometimes associated with organ pipes.

Vibrations of Rods, Discs, Bells, and Tuning Forks.—A rod fixed at both ends vibrates transversely as a string in some circumstances, with this difference, that the series of tones emitted by the string is as 1 : 2 : 3 : 4, &c.: while in the case of the rod it is as the squares of the odd numbers, 3, 5, 7, &c. A rod free at one end can vibrate as a whole, or in segments. Vibrations of fundamental tone are to vibration of first harmonic or overtone as 4 : 25, and so on, proportional to the squares of the odd numbers. A musical box is a good example of this class of

instrument. The rods or reeds are fixed at one end. A rod fixed at both ends will also give vibrations; the middle section curves, and the ends fan-like forms. The glass harmonica is an example of this class of rods. There are, of course, two nodes at the points of rest, and beginning with these the series of tones are again as the square of the odd numbers.

The transition from the latter class of rods to the tuning fork is easily made with the help of *Fig.* 10.

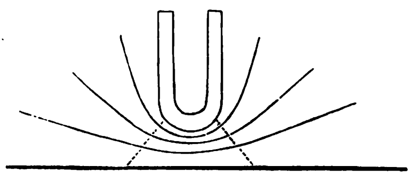


Fig. 10.

The vibrations possible to a tuning fork are—

1st.	One node on each prong.			
2nd.	„	„	and two at the bottom.	
3rd.	Two nodes on each prong, and one at the bottom.			
4th.	„	„	two	„
5th.	Three	„	one	„

The overtones rise with great rapidity compared with those of a string: as the squares of the odd numbers.

3.	5.	7.	9, &c.
9.	25.	49.	81, &c.

The vibrations of a disc are beautifully exemplified by Chladni's figures :—

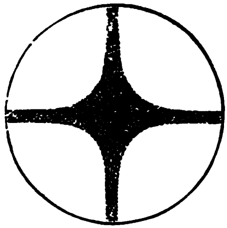


Fig. 11.

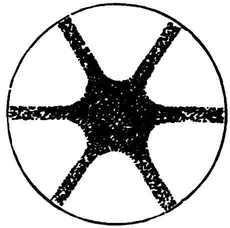


Fig. 12.

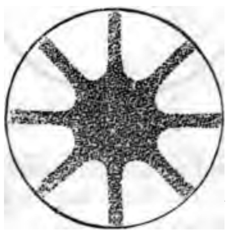


Fig. 13.

Fig. 11 is the simplest figure, and represents the lowest note. The centre line of the vibrating segment is 45° from the node in each of the quadrants.

Fig. 12 represents the next figure and the next note above. The vibrating segment is 30° from the node.

Fig. 13 gives a more complex figure, the segment being $22\frac{1}{2}$° from the node.

The disc may be further divided into any even number of segments. The larger the number, the more acute the note. In a disc the rate of vibration is dependent upon the thickness and diameter of the plates. It is directly proportional to the thickness, and inversely proportional to the squares of the diameters.

Bells have their nodes and ventral segments. *Fig.* 14 shows the transverse and longitudinal vibrations of

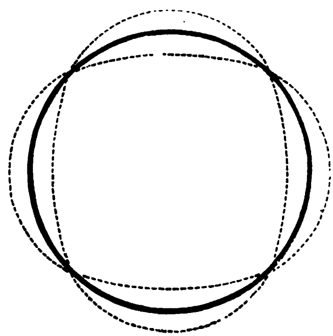


Fig. 14.

a bell which extend up the sides and over the bow of the bell. As in a disc, there may be any even number of vibrating segments.

4.	6.	8.	10.	12, &c.
2.	3.	4.	5.	6, &c.

The lower line of numbers are those the squares of which are the ratios of the rates of vibration. For instance, suppose for the lowest note the number of vibration is 40, or 4 times 10; then for six or eight sections the rates will be 90, 160, and so on.

The Human Ear.—The waves of sound pass into the external ear, strike the tympanum or drum in the middle ear, and this motion is then communicated to the hammer bone, then to the anvil bone, and next to the stirrup bone. The motion of this is now communicated to the *Fenestra ovalis*, which communicates it to the fluid in the labyrinth, and by it the motion is continued to the auditory nerve. There is

a connecting passage between the middle ear and the mouth called the Eustachian tube, which relieves the external pressure on the tympanum.

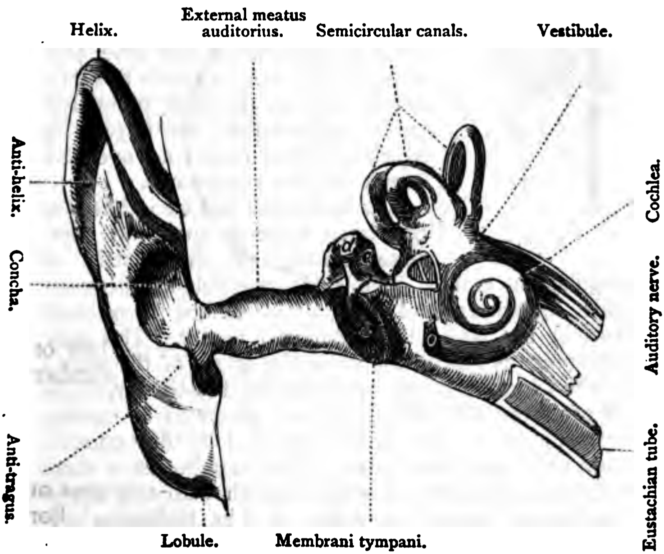


Fig. 15.—General View of the Human Ear.

d. Head of malleus, or hammer-bone.
e. Incus, or anvil-bone, at the end of which is the stirrup or stapes.
f. Fenestra ovalis, or semicircular ducts.
g. Fenestra rotunda, or snail's shell.

The Human Voice.—This is one of the most perfect of reed instruments. As the air rushes upwards through the larynx it comes in contact with the vocal cords which stretch across the opening,

Fig. 15*a*.

giving a slit-like passage called the glottis. It is the vibration of these cords which gives flexibility and variety of tone to the voice. The tighter we draw them across, the more acute will be the tone produced. *Fig.* 15*a* illustrates this part of the larynx; the other numbered parts representing cartilages by which we have command over the larynx and the vocal cords.

The sweetness and smoothness of the voice depend upon the complete closure of the glottis at regular intervals. The great resemblance between this apparatus and the syren before mentioned cannot but strike the thoughtful reader. The only difference is that in the voice the origin of the sound is the vibration of the cords imparted to the air, while in the syren the puffs of air are produced by cutting columns of air into small parts, and by their concussion setting air in vibration. For experiment, a short tube of wood, for blowing through with the upper part nearly closed by strips of thin leather, which may be tightened or relaxed, while the pipe is in the mouth, by means of two bits of cork as holders glued to the leather. This will give a fair illustration of the varieties of sound to be obtained by tightening or relaxing the membranes. (*Fig.* 16.)

Resonance.—Take a long solution glass; pour in water and sound a tuning fork at the mouth until you notice a great addition to the sound of the fork: this is called resonance. In the downward journey of the prong there is a condensation in the column of air which passes to the surface of the water and rises again,

arriving at the prong just at the moment when it commences its upward motion; this gives a rarefaction in the air column which travels down and up again at the moment that the prong completes one part of its vibration. The other part gives the condensation which performs the same journey. Therefore one complete vibration of the prong, or what is the same, the length of one sound wave, is exactly four times the length of the resounding column of air.

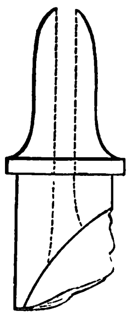


Fig. 16.

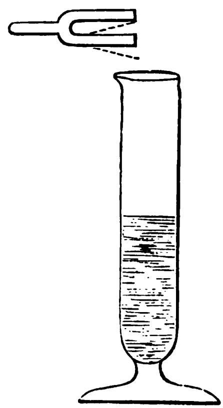


Fig. 17.

From this we may ascertain the velocity of sound if we first note by the syren the number of vibrations per second—for every vibration is equal to four times the length of a resonant column of air. (*See Exercise III.*)

The mouth is a resonant cavity. It materially modifies the voice, and its effect is easily shown when we play the common instrument, a Jew's harp. The term resonance is also applied to the confused and

incomplete return of the sound waves when we converse in an empty room.

Reflection and Refraction of Sound.—If the sound waves strike against any smooth fixed surface, they rebound from that surface, and the angle of reflection is equal to the angle of incidence. This law is the same as that which governs the reflection of all elastic bodies, and also heat and light. The analogy may be carried still further, for the laws of light as to reflection from curved surfaces and refraction through lens-shaped bodies, also apply to sound. Mirrors, plane or curved, reflect sound as well as light; and lenses may be imitated by balloon shapes of gold-beaters' skin, or some other very thin material, which, when filled with air, give the focus for sound in the same place as that for light.

An Echo is produced when the ear is able to distinguish the direct sound produced by the reflection of the sound waves. A delicate ear will perceive about nine successive sounds in one second of time,—that is to say, the sounds must not succeed each other more frequently than at intervals of one-ninth of a second of time to be heard singly. It must be understood that the sound wave in returning proceeds at the same velocity as the incident part of the wave. (*See Exercise III.*)

In order to produce an echo, the reflecting surface must be situated at such a distance from the source of sound, that the interval between the hearing of the original and reflected sound must be sufficient to prevent them being blended together. In rooms where there are curtains, stuffed furniture, and carpets, the echoes are weakened and the resonance diminished.

When sound is reflected from several surfaces, situated in different directions and at different dis-

tances, multiplied echoes are heard. A river with perpendicular walls of rock on each side reflects the sound backward and forward over the smooth surface of the water. At Lurley-Fels on the Rhine, a sound is repeated by echo seventeen times; at the Villa Simonetta, near Milan, the sound is repeated thirty times. An echo in Woodstock Park repeats seventeen syllables by day and twenty by night. If the surface upon which sound waves strike be concave, the sound may be concentrated and reflected to a point at some distance from the surface, called the focus (*Fig.* 18). If the sound waves proceeding in straight lines from the points *a b c d e*, strike upon the concave surface A B C, they will be reflected to the focus F. It is on this principle that WHISPERING GALLERIES are constructed, where the faintest whisper uttered at one point is distinctly heard at another distant point, without its being audible at intermediate positions. The proper form of these galleries is that of the ellipsoid of revolution. In such a chamber, two persons—one in either focus—can keep up a conversation with each other which is inaudible in other parts of the room.

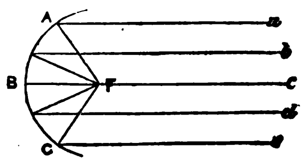


Fig. 18.

The tick of a watch may be heard from one end of the Abbey Church of St. Alban's to the other. In the Whispering Gallery of St. Paul's, London, the faintest sound is conveyed from one side of the dome to the other, but it is not heard at any intermediate point.

Halls for speaking, and churches, should be constructed so as to diffuse the sounds throughout the whole space, unimpaired by any echo or resound; and

if the speakers always occupied the same position, the parabolic form is no doubt the best. Everything should be avoided that interferes with the uniform diffusion of sounds; all needless hollows and projections should be avoided. The following simple experiment (*Fig.* 19) will illustrate the consequences arising from the reflection of the rays of sound from the interior of a parabola. Place a watch in the focus A of a parabolic mirror, and all the sound rays that fall on the concave surface will be reflected in the direction indicated by the arrows. The ticking of the watch will be distinctly heard within the space M N O P, in which the rays fall; but it will not be perceptible at a small distance on either side. Now place the reflector O P opposite to M N, and at some distance from it; the sound rays will be received by it, and thrown into the focus B. If the ear, or the mouth of a hearing trumpet, be applied to this part, the ticking of the watch will be heard almost as plainly at B as at A.

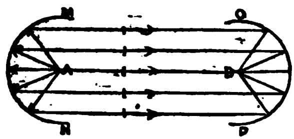


Fig. 19.

Inflection of Sound.—As waves of the sea surround a rock, rising on all sides of it with force, chiefly on the exposed side, but appreciably on the remaining three sides, so waves of sound in meeting with obstacles surge around, and their effects may be seen on the side remotest from the origin of the vibrations.

List of necessary Apparatus to illustrate the Science of Acoustics.

	£	s.	d.
Air-pump (Tate's) . . .	1	16	0
Speaking Trumpet . . .	0	5	0
Monochord	2	2	0
This may be easily made for .	0	10	0
Three organ pipes . . .	0	5	0
One organ pipe, with moveable slide and glass front . . .	0	5	0
Three tuning-forks . . .	0	3	0
Bell to place under receiver of air-pump	0	10	0
Holder and plates for Chladni's figures	1	0	0
Solution glass for resonance . .	0	3	6
Savart's toothed wheel apparatus .	1	1	0
A stand of wood may be constructed without difficulty.			

Additional List.

Barometer tube, with mercury properly introduced	0	10	0
Mariotte's tube . . .	1	1	0
The syren (Ladd's) . . .	2	10	0
Tube to imitate the larynx . .	0	5	0
Tuning-forks with mirrors attached .	3	0	0
Glass vessel with stopcock, to ascertain weight of air . . .	0	10	0
Stethoscope	0	2	6

LIGHT.

Optics is that branch of physics which treats of the phenomena of light. The sensations of external objects are derived chiefly through our sense of sight. The nature of light is, in some degree, still doubtful.

Two theories have been advanced to explain the phenomena of light,—the corpuscular or emission theory, and the undulatory or wave theory.

The advocates of the corpuscular theory maintain that light is a peculiar matter projected in every direction from luminous bodies in a succession of material particles, which move with immense velocity through space, and falling on the retina of the eye produce the sensation of light. This theory has been sustained by Newton and Laplace; but certain difficulties in some recently discovered properties of light, especially with regard to its polarization, have tended to revive the undulatory theory, viz., that all the phenomena of light depend on the undulations of an extremely attenuated and highly elastic medium called ether. This ether permeates all bodies and pervades all space, and when acted on by luminous bodies is thrown into a succession of pulsations or waves, which are propagated in every direction, and constitute the phenomena of light. These ethereal waves are admitted into the eye, and the sensation of sight arises from the motions which these waves communicate to nerves which are spread over the internal surface of that organ. We therefore see by a principle in every respect analogous to that by which we hear; the only difference being in the nature of the medium proper to excite these different sensations. In the one case the ether agitates the nerves of the eye; in the other the air communicates its vibrations to the ear.

This theory has been ably maintained by Euler and Descartes. Almost all the leading principles regarding light may, however, be explained by either theory. Both assume the existence of a subtle fluid or ether, and the influence of luminous bodies.

The velocity of light was first determined by Von Römer, a Swedish astronomer, in 1675, by observations on the satellites of Jupiter. This planet is surrounded by several satellites, or moons, which revolve about it in certain definite times. As they pass behind the planet they disappear to an observer on the earth, or, in other words, they undergo an eclipse. The earth revolves in an orbit about the sun, and in its revolution is at one point 192 millions of miles nearer to Jupiter than when it is in the most distant part of its orbit. Suppose a table calculated by an astronomer at the time when the earth is nearest to Jupiter, ignoring the fact just mentioned, showing for six months the exact time when a particular satellite would be eclipsed. In the space of six months from that time, the earth, in its revolution, has arrived at a point in its orbit 192 millions of miles more remote from Jupiter than when the table was calculated; and it would be found that the eclipse of the satellite would occur 960 seconds later than the calculated time. This is explained by the fact that the light has to pass over a greater space than when the earth was in that part of its orbit nearest to the planet; and if it requires 960 seconds, or 16 minutes, to move over 192 millions of miles, it will require one second to pass over 200,000 miles. When the earth in six months arrives at its former position, or 192 millions of miles nearer to Jupiter, the eclipse will occur 16 minutes earlier, or at the exact time calculated for that point previously. The velocity of light may,

therefore, be assumed as 200,000 miles per second; but more exact calculations give 192,500 miles per second. A reference to the following diagram (*Fig.* 20) will make Römer's observation much clearer:—

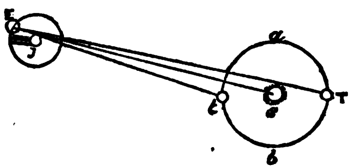


Fig. 20.

Let *S* represent the sun, and *a b* the earth's orbit; T and *t* the position of the earth at the opposite points of its orbit. *J* represents Jupiter, and E its moon or satellite, about to be eclipsed by passing within the shadow of the planet. Now the commencement or termination of the eclipse is the instant of time when the satellite enters or emerges from the shadow of the planet. If the transmission of light were instantaneous, it is evident that an observer at T, the most remote part of the earth's orbit, would see the eclipse begin and end at the same time as an observer at *t*, the part of the earth's orbit nearest to Jupiter. This, however, is not the case. The observer at T sees the eclipse 960 seconds later than the observer at *t*; and as the distance between these two points is 192 millions of miles, we have the velocity of light in one second $\frac{192{,}000{,}000}{960} = 200{,}000$.

Reflection of Light.—When the rays of light fall on any surface they may be reflected, absorbed,

or transmitted. A portion only of the light which falls on any surface is reflected; the remainder is absorbed or transmitted. When the light reflected from any surface or point of a surface to the eye is considerable, such surface or point appears white; when partly reflected and partly absorbed it appears dark-coloured; but when all the rays are absorbed and none reflected the surface is black. Charcoal is black because all the rays of light which fall on it are absorbed, and such a body is not seen unless surrounded by other bodies from which the light is reflected. Let A D (*Fig.* 21) be a ray of light which falls on a

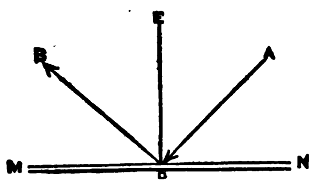


Fig. 21.

plane mirror, and strikes it at the point D. This ray will be thrown back in the direction D B, so inclined to ray A D, that if we raise from the point D a line perpendicular to M N, the angle B D E will be equal to the angle A D E. The ray A D is the incident ray, and the ray D B the reflected ray. The angle of incidence, A D E, is equal to the angle of reflection, B D E. The line D E is called a normal (Latin, *norma*, the rule). It is perpendicular to the reflecting surface.

The same law holds good with regard to curved surfaces.

If the reflecting surface is concave, or part of a

sphere (*Fig.* 22), as A B, a ray of light, C D, falling on the point D, will be reflected in the direction D E, forming the same angle with a line, F D, drawn from the centre of the sphere to the point where the incident ray falls. If the surface of the speculum be convex, the same law holds, viz., that the angle of in-

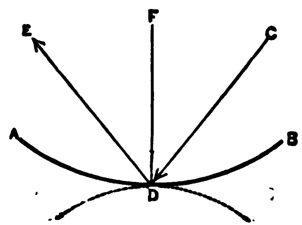


Fig. 22.

cidence is equal to the angle of reflection, and the same reasoning applies.

Definitions.—Parallel rays are those which are parallel or equidistant. Divergent rays are those which issue from a point and separate from each other, forming an angle. Convergent rays are those which approach each other, or converge to a point. A ray of light is called a luminous ray, and a luminous pencil of light is a number of rays converging to or diverging from a point. A transparent or diaphanous body allows the rays of light to pass through it, and the object is distinctly seen as in common glass. If the rays of light pass through, but the object is not seen, it is said to be translucent, as ground glass.*

* In this case the glass is roughened, and the rays in passing through are broken and confused in every possible manner, so that the object cannot be discerned by means of them.

A substance is said to be opaque, when it is impervious to the light.

Allow light from an object to pass through a small opening, and place a screen to receive the image. It will be found to be inverted. In *Fig.* 23 the ray from

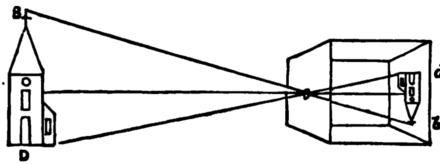


Fig. 23.

B passes to *b*, and the ray from D goes in a straight line to *d*. Hence we learn, that when light passes through small openings the images will be inverted, examples of which in optics are common. The eye is an instrument of this kind, the camera obscura, telescopes, &c. We can also here lay down the important rule, that *light travels in straight lines.*

Place a sheet of paper measuring one square foot at a distance of one foot from a candle flame. Note the intensity of the light. Then remove the paper to a distance of two feet, it will be found that only one-fourth of the amount of light falls on the paper in the second position; or, in other words, to retain the same amount of light the paper must be enlarged to four square feet. At a distance of three feet the intensity would be one-ninth, &c. In *Fig.* 24, A is the point of light, B the screen of one square foot area, C the screen enlarged to four square feet; one quarter of this screen, of the same size as screen B, will receive one-fourth of the light retained by B, *i. e.*, at double the distance the light is one-fourth the

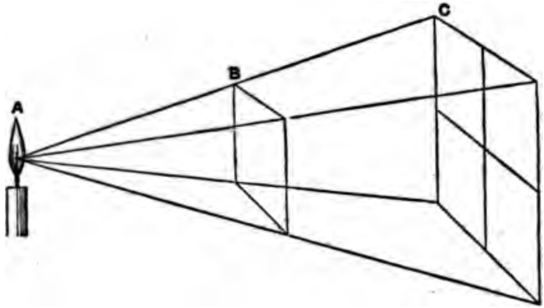


Fig. 24.

intensity. From this experiment we deduce the law, that *the intensity of light varies inversely as the square of the distance.* (*Exercise IV.*)

Shadows and Penumbræ.—In *Fig.* 25 suppose

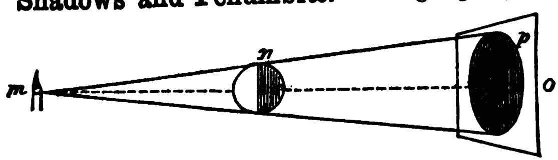


Fig. 25.

luminous rays to proceed from a point *m* to the screen *o*; in their path they meet with an opaque ball *n*, from which what is called a shadow *p* on the screen is derived. Here the light proceeds from a point, and the shadow is well defined; this is not commonly the case, for the light has generally some magnitude, and produces outside the shadow a rim called a penumbra (*almost a shadow*). For instance, in *Fig.* 26 let L represent a luminous ball and M an opaque ball, P being the screen, then the part 1 of the screen will be

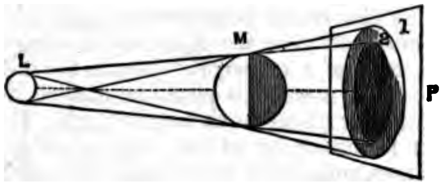


Fig. 26.

fully illuminated, part 2 partially so, part 3 will be a complete shadow. Part 2 is called a penumbra. These are geometrical shadows, natural shadows are by no means so well defined.

The relative intensities of light are ascertained by the *shadow-test*. Photometers (*light measurers*) are used. Rumford's photometer has an upright spindle

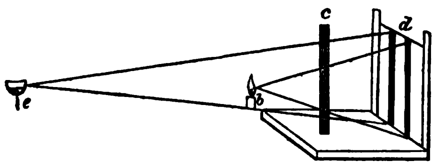


Fig. 27.

c on a wooden stand; at a short distance there is a plate of ground glass *d* in sliding grooves. To use this simple instrument, suppose a candle *b* to be at a known distance, and that a gas flame *e* is placed at three times this distance to give a shadow of the same intensity on the ground glass from the upright spindle as is given by the candle, then the intensity of the light from the gas flame is nine times that of the light given by the candle. An estimate of the power of a gaslight may be thus made, a fixed standard candle being used.

Ritchie's photometer is on the same principle. The light is admitted from the lights to be compared at opposite ends of a rectangular box, in the middle of which there is a wooden partition flanked on each side by a mirror placed at an angle of 45°. Therefore the light is thrown off at an angle of 90° with the incident rays, and passes to the upper side of the box, in which is placed a ground-glass screen to receive the two quantities of light. Here the lights to be compared are arranged so that the reflections on the glass are equal; then their distances measured; say one is at two feet, and the other at eight. Then the latter at four times the distance has equal intensity to the former; *i. e.*, its intensity is sixteen times that of the smaller flame.

Bunsen's Photometer.—A grease spot is made on bibulous paper, and the lights are placed on opposite sides until this part of the paper looks like the rest, when the distances are measured.

Wheatstone's Photometer.—This instrument gives more accurate results. It consists of a steel bead fixed on a small toothed wheel, and this again is placed on a moveable disc surrounded by teeth. By turning a handle the disc and the small wheel are made to rotate, and the bead, with the light reflected on opposite sides in turning round with the double motion imparted, gives two lines of light, somewhat in the shape of a rose. As before, these are made equal, and distances of lights measured.

Reflection of Light from Plane Mirrors.—*The angle of reflection is equal to the angle of incidence.*

The image of any point is formed behind the mirror at a distance equal to that of the given point from the mirror.

We always seem to see an object in the direction in which the rays of light enter the eye.

It is a common mistake, especially with young students, to picture to themselves the rays of light proceeding from the eye. To guard against this, bear in mind that we see objects by means of light which comes *from them*. The eye is only an instrument for receiving impressions from the light as it arrives.

A Plane Mirror is one in which the reflecting surface is plane. Ordinary plane mirrors, or looking-glasses, are plates of smooth glass with one side covered with a thin layer of mercury and tinfoil. The images formed by a looking-glass are produced by the reflection of the rays of light from the metallic covering. If the surface of a plane mirror could be so highly polished as to reflect all the rays incident upon it, the mirror itself would be invisible, and an observer would see nothing but the images of the objects before it. Such a mirror placed vertically against the walls of a room appears like an opening leading to another apartment, and a person is only prevented from walking through it by meeting his own image. We always seem to see an object in the direction in which the rays of light enter the eye. A mirror which changes the direction of the rays proceeding from an object will change the apparent place of that object. Let a looking-glass be placed horizontally on a table, and let the rays of a candle fall obliquely on the mirror and be reflected to the eye, on the opposite side we shall seem to see the candle inverted, and as much below the surface of the glass as the candle is above it. Vary the position of the candle and of the observer, drawing a diagram for each new position, which shall fully account for the apparent change of the image in position. The reader will then obtain accurate views of the lateral inversion of objects by plane mirrors.

When a person stands before a looking-glass, the rays of light which proceed from each point of his body will, after reflection, proceed as if they came from points occupying corresponding positions behind the glass, and will produce an effect upon the eye as if they had actually proceeded from those points.

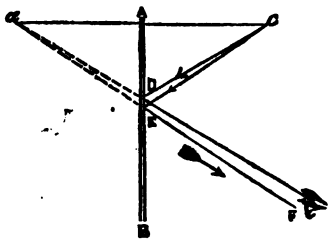


Fig. 28.

The image, therefore, appears as much behind the glass as the person is before it. Let (*Fig.* 28) A B be a plane mirror or looking-glass, and *c* an object placed before it. Let *c* D and *c* E be two rays diverging from the object, and reflected from D and E to the eye at F. After reflection they will proceed as if they had come from a point *a*, as far behind the surface of the glass as *c* is before it. The two triangles *a* D A and A D *c* are equal. For the angles at A are right angles, and the angles at D are equal by construction. The side A D is common, therefore the base *a* A = the base A *c*. (Euclid, i., 4.) Hence whatever the length of A *c*, the distance *a* A will be the same. For this reason our reflection in a mirror appears to approach when we move towards it, and retire when we walk away.

When trees or houses are reflected from the smooth

horizontal surface of a sheet of water, they all appear bottom upwards, because the light of the object reflected to our eyes from the surface of the water comes to us in the same direction as it would have done had it proceeded directly from an inverted object in the water. In *Fig.* 29 the ray of light proceeds from a cross at A, strikes the water at B, and

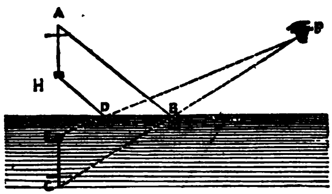


Fig. 29.

is reflected to F, and that from the base H strikes the water at D, and is reflected also to F. A spectator at F will see, in the direction of the reflected rays B F and D F, the points C and E as if the rays had proceeded directly from E and C, and the image of the cross will appear to be at E C and inverted.

On a comparatively small plane mirror, the size of which could be easily determined, a person may see the whole of his figure by standing at a distance from the surface. Let A B (*Fig.* 30) be a plane mirror.

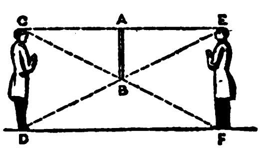


Fig. 30.

The rays of light C A, which proceed from the head

of the person, fall perpendicularly on the mirror, and are reflected back in the same line. The rays D B, proceeding from the feet, fall at an angle on the surface of the mirror, and are therefore reflected at an angle, and reach the eye in the same direction that they would have taken had they come from a point F behind the mirror.

Pepper's Ghost.—This optical illusion is entirely due to the reflected image of a living person. To produce this effect, the platform, or ordinary stage,

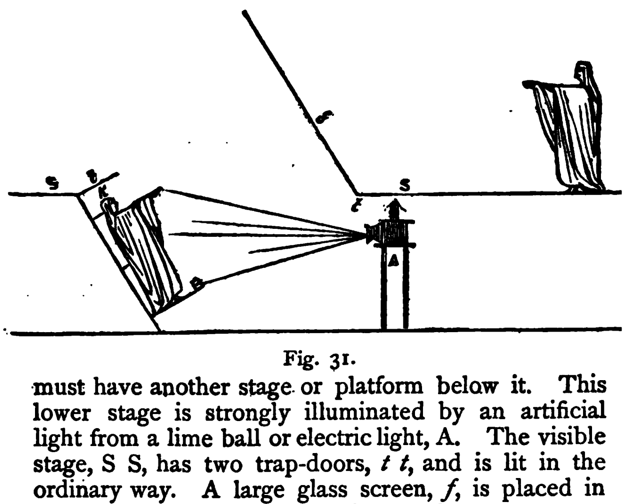


Fig. 31.

must have another stage or platform below it. This lower stage is strongly illuminated by an artificial light from a lime ball or electric light, A. The visible stage, S S, has two trap-doors, *t t*, and is lit in the ordinary way. A large glass screen, *f*, is placed in front, and at such an inclination as that persons can see the reflected image. The actor or actors corresponding to the images are hidden from the audience by being on the lower stage, B. The person or persons acting are strongly illuminated, and the light is

so managed that it may be instantly masked or extinguished, so as to make the image appear and disappear at pleasure. The raised part of the trap-door in front of the ordinary stage helps to screen the light from the audience. The actor, while on the stage B, leans against a screen, *k*, covered with black cloth, and parallel to the glass screen, *f*. The scenery is so arranged as to hide the frame of the glass, *f*, and under a subdued light the glass and frame may be either raised or lowered out of sight, so as to allow a person to pass across the space which the glass occupied, and thus make the illusion more perfect. In order that the image should appear upright on the visible stage, the person on the lower stage should be so inclined as to be parallel to the glass screen; and as the person acting cannot see his own image, marks are made on the lower stage, so that he may know the position of his image with reference to the audience.

Angular Velocity of a Reflected Ray.—Let *m n* be a graduated arc on the top of a table. O a mirror, moveable in connection with a spindle O A. Let the arc be graduated from 0 to 20. Then place the index at 0 and allow a ray of light to pass along it,

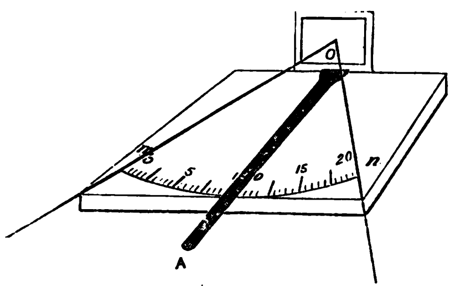


Fig. 32.

the ray will return upon itself. Now move the index to 1, then, as the angle of reflection is equal to the angle of incidence, the ray will return to 2. Place index at 2, ray returns to 4. Index at 3, ray is found at 6, and so on, the number for the ray increasing 2, for the index 1. This is usually expressed thus: *the angular velocity of a reflected ray is twice that of the mirror which reflects it.*

Multiplication of Images by Angular Mirrors.—Take two common plane mirrors, set them upright, with their reflecting surfaces towards each other at an angle of 90°. Place a candle between them; three images of the candle will be seen. At 60° five images may be obtained; at 45°, seven images, and so on. Now place them directly face to face at a short distance, with a candle between them; look over the top of one mirror into the other, and innumerable images will be seen,—theoretically, they are endless. It is useful to have the frames of the mirrors one white and the other black, and then the reason of the phenomenon is much better understood. It is caused by the reflection and re-reflection of the image from one mirror to the other. Tradesmen anxious to increase the extent of their premises indefinitely, sometimes have recourse to this idea; they place a large mirror at each end of the shop, and of course, as in the case of the candle, their premises are apparently multiplied a thousandfold.

The Kaleidoscope is founded on this multiplication of images by angular mirrors. Usually three mirrors are placed so as, in section, to form a triangle with angles of 60°, in a circular tin case. Whatever image is produced at one corner is multiplied five, ten, or any other number of times, according to the angle, giving a complete geometrical figure made up by this number of triangles with their apices in the centre.

Mirrors are commonly, when not plane, concave spherical, convex spherical, or concave parabolical. The first two are portions of either the external or internal surface of a sphere: if the reflection is from the external surface it is called convex; if from the internal, concave.

Let the annexed figure represent a concave spherical mirror, then, the following definitions being clearly mastered, we will proceed to illustrate a previously given simple but most important law,—*The angle of reflection is equal to the angle of incidence.*

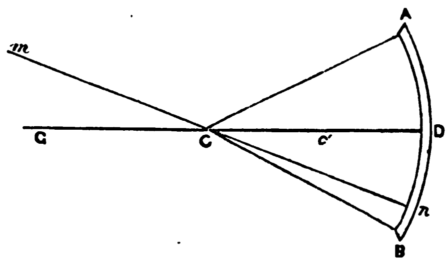


Fig. 33.

Here A B represents a portion of a spherical concave mirror, that is, a portion of a sphere whose centre is at C. The point C is called the geometrical centre, or centre of curvature. D is the centre of the surface of the mirror. The line G D passing through these two centres is called the principal axis. Point *c′*, midway between these centres, is named the principal focus; *m n* is a secondary axis, which must always pass through the centre of curvature. Angle A C B is called the angle of aperture. The normal in a

sphere is a line drawn from the circumference to the centre, as A C or B C.

The position of the focus we will show by the following diagram.

The surface of a curved mirror may be looked upon

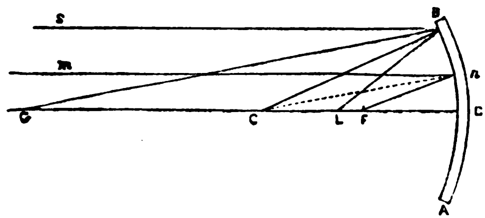


Fig. 34.

as an infinite number of small plane mirrors, and a parallel ray, *m n*, falling upon the surface of the mirror A B, will form, with the normal C *n*, an angle of incidence, *m n* C, and the reflected ray *n* F will fall at an equal angle C *n* F, so as to strike the principal axis in F, midway between C and D.

Cases 1 *and* 2. All parallel rays striking the surface of such mirror will be reflected to the principal focus F, if the angle of aperture do not exceed 10°; conversely, when the source of light is placed at F, the reflected rays are parallel.

Let us now consider the case when the source of light is at a point G, and consequently the rays do not pass as parallels to the mirror. Suppose G B to be such ray. Then it is evident that the angle of incidence, G B C, is less than if formed by the parallel ray S B. Consequently the angle of reflection is less, and the focus is formed at L, between the principal focus

and the geometrical centre. (*Case* 3.) As the point of light G is moved up to C, so L moves towards C, and if light G is moved to position of L then focus L will move to position occupied by G. (*Case* 4.) They are therefore reciprocally related to each other, and hence are named conjugate foci.

When points L and C coincide, the rays are, as it were, focussed on the source of light itself. (*Case* 5.) If the light be placed between the principal focus and the mirror, then a virtual focus will be formed behind the mirror.

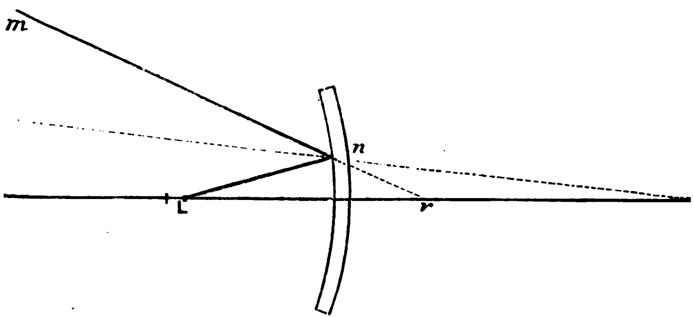


Fig. 35.

Let L *n*, *Fig* 35, be the incident ray, then L *n* C is the incident angle, and C *n m* the angle of reflection. Continue this line behind the mirror to the principal axis, and we find that the focus—virtual, not real—is at the point *r*. (*Case* 6.)

Note that the principal focus is immoveable, while the conjugate or virtual foci vary in position as the light varies.

Lastly, in the case where the source of light is not

on G D, draw a secondary axis from the light through the geometrical centre of the mirror. Then the whole of the remarks made as to foci on the principal axis apply equally to every secondary axis, and most useful exercises may be made by following out the foci along secondary axes with the light in various positions *upon* them.

Images of Objects with Concave Mirrors.—Carrying out the laws last laid down as to points which reflect light and their foci. To obtain the focus of an object and so get a distinct image we have but to bear in mind that objects are made up of points which reflect light, and apply the above rules.

Case 1.—The sun's light being so generally diffused, it may be looked upon as striking objects in parallel lines, and with such light, the image is formed at the principal focus.

Case 2.—Of course it is at once seen that in the converse of the latter there will be no image.

Cases 3 *and* 4.—These come more pointedly within our experience, and may be readily demonstrated by means of a small concave mirror, or even the inner surface of a bright spoon. In *Fig.* 36 let A B be a candle in front of a concave mirror D E. Draw a

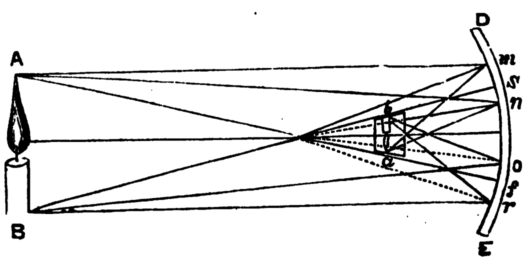


Fig. 36.

secondary axis, A *f*, from A, and another one, B *s*, from B. Then it will be found that rays A *m*, A *n*, will return to *a*, and rays B *r*, B *o*, will return and cut the secondary axis in *b*. Between these two points all the other points of the image would fall when treated similarly, therefore we conclude that in *Case* 3 an image smaller and inverted would be obtained, while in *Case* 4, when *a b* is the light, the image would be the reverse as to size, but still inverted, as A B.

In *Case* 5, where the candle is placed at the centre of curvature, the rays would return and focus upon the object.

Case 6.—When the object is between the principal focus and the mirror. Here C *a* and C *b* are the

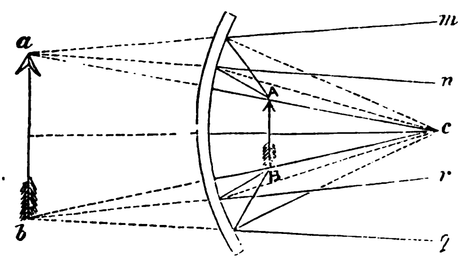


Fig. 37.

secondary axes continued. The reflected rays *m a*, *n a*, cut *c a* in *a*, which is the focus of point A; and rays *r b* and *q b* cut *c b* in *b*, which is the virtual focus of point B. We have, therefore, a virtual image *a b* of the object A B—upright and larger.

When the object is above the principal axis, as in *Fig.* 38. From A and B draw secondary axes, and then the reflected rays will cut them in *a* and *b* respectively. The image is smaller and inverted.

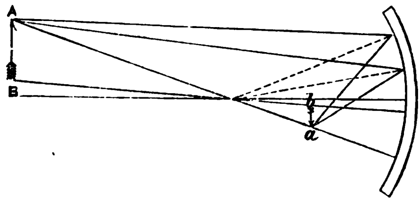


Fig. 38.

Images of Objects in Convex Mirrors.—The student will be able to understand the phenomena of reflection in convex mirrors by aid of the following figure. Bear in mind that convex mirrors have no real foci, but virtual; that is, their foci do not exist, but their positions may be ascertained by continuing the lines of reflection to the interior of the sphere, or to the back of the mirror, as in plane mirrors.

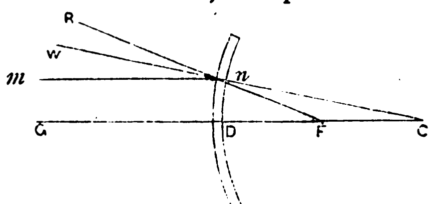


Fig. 39.

In the above figure G D C is the principal axis; C the geometrical centre; C W is the normal continued, *m n* the incident ray, and *n* R the reflected ray, which, continued to the principal axis, is focussed in F, as in the concave mirrors, midway between the geometrical centre and the centre of the surface of the mirror. These mirrors are sometimes called dispersing mir-

rors, because all the rays of light which fall on them are reflected in a diverging direction.

Determination of the Principal Focus.—It is often necessary to find the radius of curvature, which of course is double the focal distance. To obtain this distance from a concave mirror, cause the rays of the sun to be reflected from the mirror to a ground glass screen; move the screen until they converge and give a bright luminous spot; then the distance from the mirror to the screen is the true focal distance.

In a convex mirror, to determine the principal focus is a more difficult matter, because it is virtual. Cover the mirror with paper, leaving two small holes; allow the reflected light from these to fall upon a ground glass screen; move the screen backwards until the distance between the two luminous spots on the screen is exactly double that between the openings on the mirror. The mathematician will at once see that the distance between the mirror and the screen, reckoning from the mid point between the luminous spots in each case, represents the focal distance of the mirror.

So far we have considered points chiefly; to understand the formation of figures by these mirrors it is only necessary to imagine the figure to be made up of a series of points, and to judge of their position according to the principles already laid down. The student is advised to practise this part of the subject by drawing various figures in different positions as constantly seen by the eye.

Application of Mirrors. — Ordinary mirrors are too well known to require alluding to. Concave mirrors have been employed as burning mirrors, —that is, for concentrating the heat of the sun's rays on an inflammable substance. They are used in

telescopes, and an instrument called the heliostat is formed by mirrors arranged so as to move in any direction, and throw the sun's light in any required course. For lighthouses such mirrors have been used, though they have been supplanted by parabolic mirrors, which prevent the diffusion and consequent weakening of the intensity of the light. A little thought will readily suggest to the student that a parabolic mirror will reflect the rays of light in straight lines, which is not the case with a concave mirror. The difference is not great, but appreciable in long distances.

Aberration of Sphericity by Reflection. Caustics.—When the angle of aperture exceeds 10° it will readily be seen that the successive reflections will cross each other instead of coming to a focus at a certain point; and the places where they cross being united by a line drawn through them will give a curve, which is called a caustic by reflection, to distinguish it from a caustic by refraction, which will occur in the description of lenses. The caustic is said to be caused by aberration of sphericity.

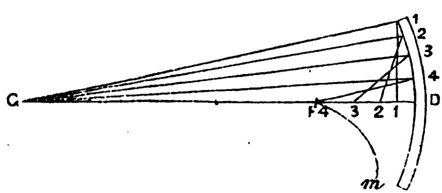


Fig. 40.

The ray G 4 will be focussed at F. G 3 a little nearer the mirror, so as to cross line 4 F. G 2 still a little nearer, and so on. This is called aberration

of sphericity by reflection; the line joining the crossing points, as F *m*, is termed a caustic.

Refraction of Light.—The bending or deviation which the rays of light undergo in passing from one medium to another is called refraction. A medium, in optics, is any substance through which light can pass. In optics, a medium is either dense or rare, according to its power of refracting light, and not according to its specific gravity. For instance, alcohol, olive oil, and turpentine have a less specific gravity than water, but have a greater refractive power. The laws which govern the refraction of light are as follow:—

1. The planes of incidence and refraction coincide, both being normal to the surface separating the media at the point of incidence.

2. The sine of the angle of incidence is equal to the sine of the angle of refraction multiplied by a constant quantity.

The constant quantity referred to varies with the media, but is the same for any given medium. It is called the *index of refraction*.

Let A be the point of incidence in a line separating air from water. With A as a centre, describe the circle B *m* C *p*. Let L A be an incident ray, and A *k* the refracted ray. Draw *m n* and *p q* perpendicular to the normal B C. Then will these lines bear the same proportion to each other that the sine of the angle of incidence bears to the sine of the angle of refraction, and we shall have, in the particular case of air and water, *m n* equal to *p q* multiplied by 1⅓, whatever may be the inclination of L *k*.

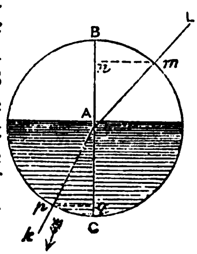


Fig. 41.

Here $1\frac{1}{3}$ is the index of refraction. For air and glass the index of refraction is $1\frac{1}{2}$. Suppose the ray of light to be passing from water to air, then the sine would be reduced in the same proportion as it is here increased, and the same consideration must be borne in mind with regard to glass or any other substance.

A straight stick partly immersed in water appears broken or bent at the point of immersion. This is owing to the fact that the rays of light proceeding from that part of the stick under water are refracted, or deviate from a straight line as they pass from the water into the air. That part of the stick in the water will appear lifted up or bent in such a way as to form an angle with the part out of the water.

The annexed diagram will assist the student to understand this. A B represents the true position of the stick; A *n* C its apparent position. The dotted lines proceeding from the part immersed represent the rays which on emerging from the water are refracted, so as to enter the eye at *m*. The eye sees in the direction of the rays, and therefore these rays, continued in

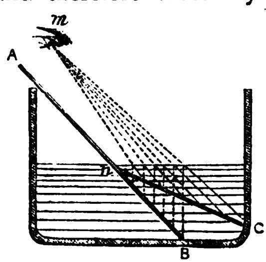


Fig. 42.*

* The engraver has given the lines from B *n* to the surface perfectly vertical, if so they would not be refracted at all. Imagine them to be slightly oblique.

straight lines through the water, give the apparent position *n* C of *n* B.

A spoon in a glass of water, or an oar partially immersed in water, always appears bent. A person endeavouring to strike a fish under water must, unless he be immediately above it, aim at a point apparently below it. Let a shilling be placed at the bottom of a basin, as at *a* (*Fig.* 43), in such a manner that the eye

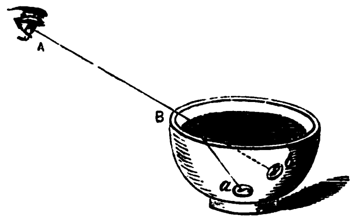


Fig. 43.

at A cannot perceive it. Then let some one fill the basin gently with water, so as not to disturb the shilling. The coin now rises into view, just as if the bottom of the basin had been elevated. It will, by the refraction, be seen not in its true place, *a*, but in the direction A B. The rays from the shilling, on entering the air, which has a much less refractive power than the water, are turned towards the surface of the water; and of the rays so emerging, some will proceed to the eye, and the image of the shilling will appear in the direction of the ray entering the eye. A clear stream, viewed obliquely from the bank, appears more shallow than it really is, since the light, appearing from the objects at the bottom, is refracted as it emerges from the water. The depth of water, under such circumstances, is about a third more than it appears—a useful fact for boys to bear in mind when bathing.

All gases, including air, refract the rays of light according to their density. The light, on entering the atmosphere, is refracted according to its density; and as that portion of the atmosphere nearest the surface possesses the greatest density, it must also possess the greatest refractive power. From this cause the sun and other celestial bodies are never seen in their true position unless they happen to be vertical, and the nearer they are to the horizon, the greater will be the influence of refraction in altering their apparent places. Morning does not occur at the instant of the sun's appearance above the horizon, nor does night commence the instant the sun disappears below it. Both at morning and evening the rays proceeding from the sun below the horizon are refracted by passing through the atmosphere, or bent down towards the surface of the earth. As the density of the air diminishes from the surface of the earth, there is not that sudden change of direction we observe in a stick partly immersed in water; but a ray of light proceeding from any celestial body describes a curve, being more and more refracted at each step of its progress through the atmosphere. This also applies to light received from distant objects on the surface of the earth which are higher or lower than the eye.

Total Reflection.—When light passes from a medium to one more refractive it will always be refracted; but not so when it passes into a less refractive medium, as when it passes from water or glass into air. In this case the angle of incidence is limited, beyond which refraction cannot take place. Let B M C represent a hollow globe half full of water. A ray of light coming from L to A, being normal to the surface of the globe, experiences no refraction on entering the globe; but on reaching A, if the angle of

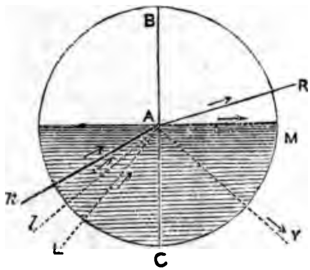


Fig. 44.

incidence L A C is small enough, it will be refracted from the normal B A, and pass out into the air in some such direction as A R. But if the angle be increased, as *l* A C, then, the refraction decreasing, we shall have the ray passing out at right angles to B A, along A M. The angle *l* A C is then the *limiting angle of refraction.* From water to air this angle is 48° 35′. From glass to air, 41° 48′. It is evident then if the angle exceeds 48° 35′, as is the case with the ray *n* A, that it will not pass out of the water at A,—in other words, will not be *refracted* at all, but it will be totally or internally *reflected* in some such direction as A *r*.

This kind of reflection at the surface which separates two media is called internal or total reflection. It is called total reflection because all the light is reflected, which is not the case under any other circumstances of reflection, no matter how carefully the reflecting surfaces may be polished.

Total reflection may be observed by the following simple experiment.

Let A represent a coin placed beyond the limiting angle of refraction. Rays passing to the surface of the water in the glass vessel are internally reflected,

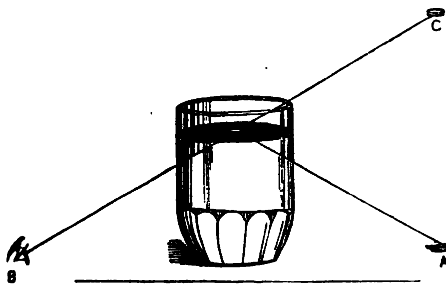


Fig. 45.

as if the surface of the water was a mirror with face downwards. They strike the eye at B, and image of the coin is seen in the direction B C.

Mirage.—The term "looming" is applied sailors to a curious optical deception by which obj come into view, though materially altered as to t shape and position. The French call it "*mira* the Italians, "*fata morgana.*" It often happens ships appear as if painted in the sky, and not res upon the water. Rocks and sands appear ra above the surface. The Swedes long searched fo illusory island of this sort, which they saw from a tance placed between the isles of Aland and the c of Upland. In the unusually hot summer of 18 "mirage" of the coast of France, extending s miles, was seen from the opposite English shores.

These phenomena are due to the varying der of the different strata of the atmosphere lying the surface of the earth. Rays, therefore, procee from distant objects and passing through these st of different density, will be unequally refracted, proceed in a curvilinear direction until they strik upper stratum at such an angle as shall proc

internal reflection; and in this way an object behind a hill or below the horizon may become visible, and appear suspended in the air.

Suppose the rays of light from a ship (*Fig.* 46) below the horizon to pass through layers of the atmosphere of different density, as A B C.

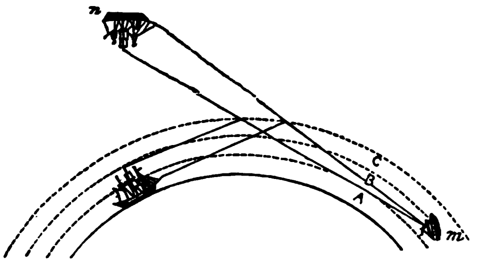


Fig. 46.

On attaining the extreme of layer C the angle of refraction passes the limit, and the rays become totally reflected. Then, as an object always seems to be in the direction in which the last rays proceeding from it enter the eye, an inverted image will be seen in the direction *m n*. Again, the rays may be so reflected as to give an upright image of the object. For example, the rays may be reflected so as not to cross each other, and then the position of the image will be upright. Occasionally at sea, but more commonly on the hot sandy plains of Egypt and Africa, ordinary objects are seen by means of horizontal rays, and below them inverted images of the objects, just as reflections of trees, &c., on the banks of a stream are seen by an observer on the opposite shore. These are caused by a reversal of the ordinary arrangement of the strata of the atmosphere. Consequently, rays in proceeding from the object are refracted in such a

manner as to reach the limiting angle, and then become totally reflected, as in the preceding example.

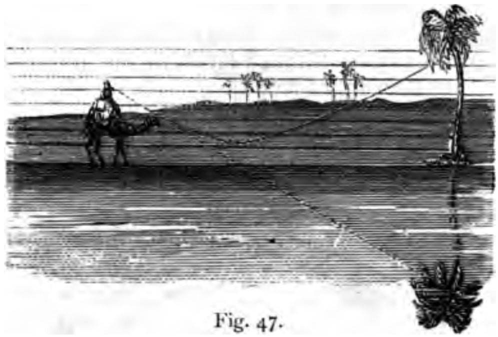


Fig. 47.

The diagram (*Fig.* 47) will assist the student in understanding the latter phase of the "mirage."

These effects may be illustrated by heating an iron rod and then placing it in a horizontal position. The air in contact with the upper surface of the iron will be more rarefied than that at some distance above it, and thus the order of density will be to a small height inverted; consequently, in looking horizontally along the bar to any object a little height above it, its direct image will be seen by means of horizontal rays, and an inverted image will be seen below it by reflected rays.

A ray of light passing through a medium whose two sides are parallel will suffer little change by refraction, since the second face or surface exactly compensates for the refractive effect of the first.* Let A B (*Fig.* 48) represent a section of a plate of glass,

* Although some little difference of position takes place, owing to the thickness of the glass, yet glass is generally so exceedingly thin that this forms no appreciable change in the position of the object.

and C D a ray of light incident upon it. It will be

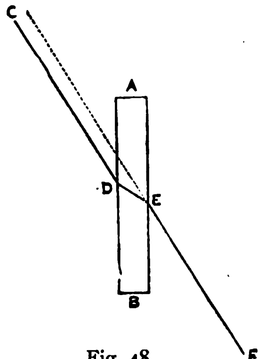


Fig. 48.

refracted in passing through the glass, and again on emerging in the direction of the line E F, parallel to C D. Hence, in looking through a window, if it has good glass we do not see the position of objects changed.

If the bounding surfaces of the medium through which light passes be not parallel, the direction of every ray passing through it is permanently altered, and the greater the inclination of the two surfaces, the greater the alteration.

A Prism.—In optics a prism is a transparent medium enclosed between two plane faces inclined at an angle towards each other. On looking through a prism all objects appear removed from their true position. Let C A B (*Fig.* 49) be a section of a prism, and *a c* a ray of light incident on it. In passing through the prism it will be refracted towards the normal, or in the direction of the base of the prism, because glass is more refracting than air. Again, on

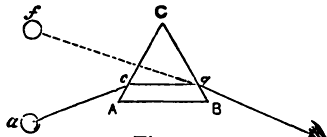


Fig. 49.

emerging it will be refracted from the normal, *i. e.*, towards the thickest part of the prism, becauses it passes into a less refractive medium, and will take the direction from *g* to the eye; and as objects always appear in the direction in which the last ray enters the eye, the object *a* will appear at *f*—that is, *objects seen through a prism appear deflected towards its summit.* It will also be shown in speaking of colour that objects seen through a prism appear in all the colours of the rainbow.

Lenses.—A lens is a refracting medium bounded by curved surfaces, or by one curved and one plane surface. Lenses are usually made of glass. There are six kinds of lenses, named according to the nature of the bounding surfaces.

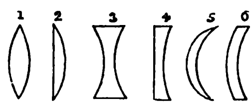


Fig. 50.

1 is a double convex lens, bounded by two convex surfaces. When the curvature of the two surfaces is the same, the lens is said to be equally convex.

2 is a plano-convex lens.
3 is a double concave lens.
4 is a plano-concave lens.
5 is a converging meniscus } both concavo-convex.
6 is a diverging meniscus }

Nos. 1, 2, and 5 are thicker in the centre than at the edges. These collect the rays of light, and are convergent lenses. Nos. 3, 4, and 6 thinner in the middle, and are named divergent lenses. The centres of the bounding surfaces of a lens are the centres of curvature, and straight lines through the centres of curvature are called the principal axes of the lenses.

Spherical lenses are used in optics. They are made of crown or flint glass, the latter containing more lead and being more refractive. It has already been stated that rays of light passing through a prism are deflected towards its base, and if we imagine that in lenses 1, 2, and 5 the summits are outwards, and in 3, 4, and 6 inwards, as in *Fig.* 51; we then see that the first three condense the rays while the others disperse them.

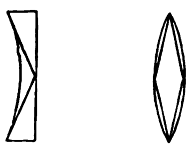


Fig. 51.

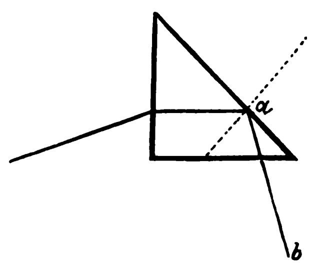


Fig. 52.

When a ray of light enters a prism, it does not follow that it will always be refracted. It may be totally reflected, as in *Fig.* 52, where the ray enters the glass at such an angle as to be refracted on entering; but on arriving at the opposite surface it strikes at an angle which is beyond the critical angle for glass into air (41° 48′). Therefore it cannot pass, but is totally reflected in direction *a b*.

Action of Lenses.—In explaining the action of lenses on light, it is only necessary to take the double convex and double concave lenses, as the others are only modifications of them, and have the same effects, only in a different degree.

It will be well to recall what has been said about concave mirrors and their foci here, for double convex lenses have the same foci, real and virtual.

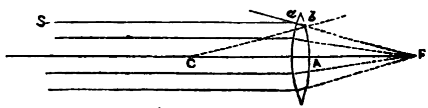


Fig. 53.

Case 1.—Let us suppose that the luminous rays are parallel, they will on passing through the lens be twice refracted towards the normal, as at *a* and *b* of the ray S *a*. All the other rays are similarly refracted, and cut the principal axis in F, which is the principal focus. F A is the principal focal distance when the angle of aperture is not above 10° or 12°. With the same lens the focus is at the same distance, but varies with the refractive power of the glass and the curvature of the lens.

Case 2.—Let the rays emanate from a point sufficiently near to form a pencil of rays. *Fig.* 54.

It will be readily seen that ray S *a* makes with normal *a* F a greater angle than ray N *a*, consequently when the second refraction takes place the latter ray emerges higher, and will be focussed at a point *e* beyond the principal focus: *e* is the conjugate focus of N, for all rays proceeding from N will find their focus at this point. *Case* 3.—If the light be placed at *e* the focus will be at N. The word conjugate refers to this relation between them.

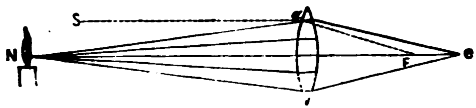


Fig. 54.

If N be moved nearer the lens, focus *e* moves further away, until (*Case* 4) when N is placed at the centre of curvature the rays emerge on the opposite side in parallel lines, and there is no focus.

Case 5.—Let N be placed between the principal focus and the lens. *Fig.* 55. Then its rays will be twice refracted, and emerge at an angle *S r c* much larger than the angle *p r c*, produced with the normal by the ray from the principal focus; and as that was parallel this is divergent, and to obtain its focus we must continue it backwards to the same side of the lens as N to the point V, which of course, being on the same side as N, will be a virtual focus.

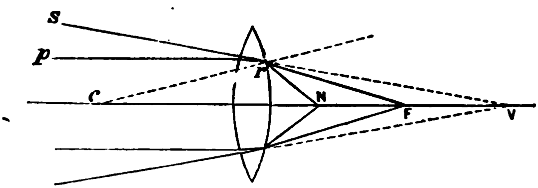


Fig. 55.

Case 6.—In concave lenses there are only virtual foci, whatever the distance of the object. In *Fig.* 56 let *p r* represent a parallel ray. It is twice refracted and emerges as part of a divergent pencil, the focus of which is at F. It will form a useful exercise to vary the position of the light, and to draw diagrams to show the different foci. The student will find no

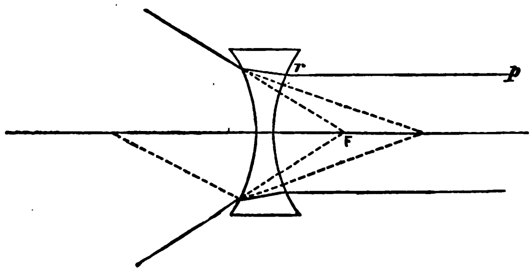


Fig. 56.

difficulty after thoroughly understanding the cases already given.

Spherical Aberration by Refraction.—In speaking of lenses, so far, it must be understood, as in the case of mirrors, that the angle of aperture does not exceed 10° or 12°. If it does so we shall have the phenomena of spherical aberration by refraction, and the caustic lines will also show. With a lens of large aperture, cause an image to pass through and fall upon a glass screen. The outside rays will not come to the general focus, but fall slightly short, cutting the preceding lines and focussing nearer the lens. So that when the image is distinct at the centre the edges are indistinct, and when clear at the edges the middle of the figure is clouded and indistinct. In photography this difficulty is serious, and is avoided by placing a circular diaphragm so as to cut off the rays at the edge. It may also be overcome by combining lenses of varying curvature.

The Eye is a collection of refractive media which concentrate the waves of light proceeding from every point of an external object on a tissue of delicate nerves called the retina, there forming an image from

which our perception of the object arises. These media are contained in a globular envelope called the sclerotica.

Coats of Eyeball.	Refracting Humours.	Muscles.
1. Sclerotic, cornea (outer).	Aqueous.	Ciliary.
2. Choroid, iris, ciliary processes.	Crystalline (lens).	Iris.
3. Retina.	Vitreous.	

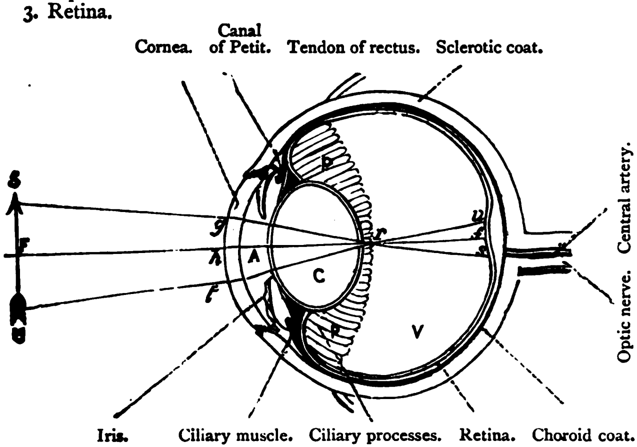


Fig. 57.—Vertical Section of the Human Eye.

A. Aqueous humour.
C. Crystalline lens.
V. Vitreous humour.
P. Ciliary processes.
S F U. Arrow.
u f s. Inverted image of arrow.

r. Focus.
S*g*, F*h*, U*t*. Rays of light before refraction.
g r s, *t r u*. Refracted rays which pass through the pupil or opening in the iris.

The shape of the eye is spherical, except just in front, where it projects beyond the spherical form. The figure represents a section of the human eye through the axis

by a horizontal plane. The part in front, as at *g* and *t*, is the cornea, which is a strong, horny, and delicately transparent coat. Immediately behind the cornea, and in contact with it, is the first refractive medium, called the *aqueous humour*, which is found to consist of nearly pure water, holding a little chloride of sodium and gelatine in solution, with traces of albumen. Its refractive power is nearly the same as that of water, and parallel rays of light having the direction of the axis of the eye will, in consequence of the shape of the cornea, after deviation at the surface of this humour, converge accurately to a point. At the posterior surface of the chamber A, in contact with the aqueous humour, is the iris, which is a circular opaque diaphragm, consisting of muscular fibres, by whose contraction or expansion an aperture in the centre, called the *pupil*, is diminished or increased according to the supply of light. The object of the iris is to moderate the illumination of the image on the retina. The iris is seen through the cornea, and gives the eye its colour.

In a small bag or capsule immediately behind the iris, and in contact with it, closing up the pupil, and completing the chamber of the aqueous humour, lies the *crystalline humour*, C. It is a double-convex lens of unequal curvature. Its density towards the axis is found to be greater than at the edge, and this corrects the spherical aberration that would otherwise exist. It contains a much larger portion of albumen and gelatine than the other humours. The posterior chamber, V, of the eye is filled with the *vitreous humour*, whose composition and specific gravity are nearly the same as the aqueous humour. At the final focus of parallel rays deviated by these humours, and constituting the inner surface of the chamber V,

is the retina, which is a network of nerves of extreme delicacy, all proceeding from one great branch, called the *optic nerve*, that enters the eye obliquely towards the nose. The retina lines the whole of the chamber V, except the portion taken up by the crystalline lens. Just behind the retina is the choroid coat, covered with a very black velvety pigment, upon which the nerves of the retina rest. The office of this pigment is to absorb the light which enters the eye, as soon as it has excited the retina, thus preventing internal reflection, and consequent confusion of vision. The last in order is the *sclerotic coat*, which is a thick, tough envelope, uniting with the cornea, and constituting what is called the white of the eye. It is to this coating that the muscles are attached which give motion to the eye.

From a little careful reflection on the structure of the eye, and by the assistance of the diagram, it will be obvious that inverted and smaller images of external objects are formed on the retina. This may be easily seen by removing the posterior coating of the eye of any recently killed animal, and exposing the retina and choroid coat from behind. The distinctness of these images, and our perceptions of the objects from which they arise, must depend upon the distance of the retina from the crystalline lens. The habitual position of the retina in a perfect eye is nearly at the focus for parallel rays deviated by all the humours, because the diameter of the pupil is so small compared with the distance of objects at which we ordinarily look, that the rays constituting the formation of images may be regarded as parallel. With age the cornea loses a portion of its convexity, and the power of the eye is diminished, and distinct images are no longer formed on the retina, the rays tending to focus behind it. Persons possessing such

eyes are said to be long-sighted, because they see objects better at a distance, and this defect is remedied by convex glasses, which restore the lost power, and with it the distinct vision. The opposite defect, arising from too great convexity, is also very common, especially among young people. The power of the eye being too great, the image is formed in the vitreous humour in front of the retina, and the remedy is found in the use of concave glasses.

The fact that images are formed in an inverted position on the retina of the eye, and yet we see these objects erect, has at various times given rise to a good deal of discussion. It is thought that the solution of the difficulty is to be found in the fact that all objects seen by the eye at one time are inverted, and therefore we do not see the inversion for want of objects with which to make comparison.

Persistence of Vision and Irradiation.—After looking at an object, the image remains on the retina for an appreciable time, variously estimated at from $\frac{1}{8}$ to $\frac{1}{2}$ of a second. The latter probably correct. Within this period, whatever succession of objects is brought before the eye, an image compounded of all will be seen. Many amusing optical toys are constructed on this phenomenon.

Rapid motion is imparted to an object, or a series of pictures drawn to show very slight advances in position towards the completion of some action. Life-like effects are thus obtained, many of which are truly surprising.

We have the Zoetrope, or Wheel of Life, the Optic wonder, the Kineograph, the Thaumatrope, &c.; whilst the various forms of colour tops combine the persistence of vision with the phenomena of colour.

Many illustrations will occur to the mind, *e.g.*, the

ing round of a lighted stick gives an image of a ›lete circle of fire—the spokes of a wheel which pidly revolving give an appearance of solidity n the outer rim, and so on. Irradiation bears ;ame relation to the eye with regard to space persistence bears as to time. For illustration, : a strip of white paper on a sheet of black r, and then a strip of black of exactly the same ı as the white strip, on a sheet of white paper, l be noticed that the white strip looks much r than the black one; in short, the image of the : strip is expanded, while that of the black ribbon ›ntracted. This is known as irradiation. The may thus often appear larger than they really The moon when horned often shows the bright apparently extending beyond the darker portion e disc, and as it were holding it in its grasp.

he Stereoscope is an apparatus .oyed to give flat pictures the arance of standing in relief. It invented by Wheatstone and imed by Brewster. When we look ı object with both eyes, each eye a different portion of it. If we at a small cube first with one then with the other, without ing the head, we shall see the ɔective of the cube different in two cases, and the nearer the the more apparent it will be. If :ube has one side directly in front ıe observer, and the right eye is :d, the other eye will see the front and also the left-hand face, but the right. If, however, the left eye is closed, the

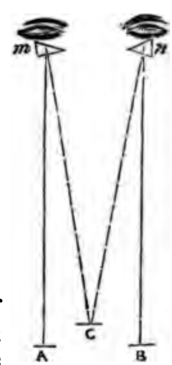


Fig. 58.

other eye will see the front face and also the right-hand face, but not the left. Hence we know that the two images formed by the two eyes are not absolutely alike. It is the difference of images which gives the idea of relief in looking at a solid body. If we suppose two pictures of any object painted on a flat surface, the one picture as it would appear to the right eye and the other as it would appear to the left, and then look at these pictures with both eyes through lenses which cause the pictures to coincide, the impression is precisely the same as if the object itself were before the eyes. The illusion is so complete that it is difficult to imagine we are looking at pictures on a flat surface. *Fig.* 58 shows the course of the rays in this instrument. A represents a picture of the object as it would be seen by the right eye alone, B a picture of the same object as it would be seen by the left eye alone; *m n* are lenses which deviate the rays so as to make the pictures coincident at C. The lenses *m* and *n* should be perfectly symmetrical, and this was attained by Brewster by cutting a double convex lens in two, placing the right-hand half before the left eye and the left-hand half before the right eye.

Analysis of Light.—We have assumed that light is a simple substance, and that all the rays are refracted in precisely the same manner, and therefore suffer the same changes when acted upon by the same media. This is not, however, its constitution. White light, as coming from the sun, or any luminous body, is composed of seven different colours, viz., red, orange, yellow, green, blue, indigo, and violet, also the index of refraction varies for each colour. These are called the primary colours, since by the mixture of some two or more of them all other colours are produced.

Sir David Brewster, from numerous experiments,

came to the conclusion that white light is composed of three colours only—red, blue, and yellow—and all others are only mixtures of these. Thus orange is a mixture of red and yellow; green, of blue and yellow; violet, of red and blue; red, yellow, and blue are named the *fundamental colours.*

The decomposition of white light, or its separation into the primary colours, is effected by means of a prism. When a ray of white light is admitted through a small hole in the shutter of a darkened room, and caused to fall upon a horizontal prism, the rays are refracted, and form on the wall or a screen the seven beams of colour just mentioned. The elongated image on the screen is called the solar spectrum (*Fig.* 59).

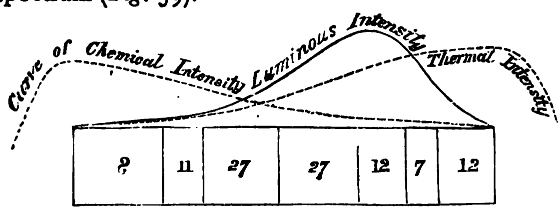


Fig. 59.

This separation of white light depends entirely upon the difference in the refrangibility of the primary colours in passing through the prism. To see this, paste a strip of red and a strip of violet paper on a black surface; on looking at them through a prism, it will be seen that the violet strip is more displaced than the red, showing the greater refrangibility of the violet rays. Those which are refracted least are at the lowest part of the spectrum, and those most, at the upper part. The red rays are the least refracted, and

the violet the most. If, by means of a convex lens or concave mirror, or another prism placed with its summit the contrary way, these coloured beams of light be collected, they will unite so as to form white light. The angle of separation between two rays produced by a prism is called the angle of *dispersion.*

Besides these coloured rays, there is an invisible space below the red where the heat is greater than at any other part of the spectrum, and a space above the violet where the chemical effect is greater. These invisible rays below the red are called *heat rays*, and those above the violet are called *actinic rays*. Neither of these rays is required by the photographer when chemical action is taking place on glass or paper; he therefore, it is well known, uses a screen or curtain of a yellow colour, to obstruct the passage of all but the yellow rays, this being the part of the spectrum which gives most light, and the least chemical or heating effect. A thermometer will show where the heat is greatest in the spectrum, and a slip of paper prepared with nitrate of silver will show the chemical or actinic effects.

Newton's Disc.—If a circular disc be painted in sections with the prismatic colours in the order in which they appear in the spectrum, it will be seen that on turning the disc rapidly by a piece of mechanism the separate colours will blend into a greyish white. A simpler arrangement may be made with an ordinary spinning top, properly coloured. The eye maintains the impression last given, for a brief space of time, consequently the different colours meet and combine on the eye. A greyish white is produced from the impossibility of mixing the colours properly, and from the unevenness of tint.

The natural colour of a body depends on the

nature and arrangement of the particles of matter of which it is composed, and not on any inherent quality of the object itself. When a ray of light falls on a body which is not transparent, it will reflect certain rays of light from its surface, and of course appear of the colour of the light it reflects. A body appears red because it reflects the red rays of light to the eye and absorbs the blue and yellow. Grass is green because it absorbs the red rays, and reflects the blue and yellow or green, and so with the other colours. Some bodies do not reflect one colour more than another, but reflect or absorb them all equally. Such are called neutral or colourless bodies. Those which reflect all the rays are white. Those which absorb all the rays are black. By changing the molecular arrangement of a body the colour may also be changed. Frequent illustrations of this kind occur in chemical experiments. For example, to a solution of iodide of potassium add a solution of chloride of mercury. The result of mixing two perfectly transparent solutions will be an insoluble salt of a brilliant scarlet colour.

Complementary Colours.—If any one of the three fundamental colours be wanting, a mixture of the other two is called the complementary colour of the one wanting, because needed to make up white light; for example, blue and yellow produce green, red is wanting. Green is called the complementary colour of red.

If a coloured wafer be fastened on a sheet of white paper, and the eye fixed steadily upon it, a ring of coloured light will, when the eye becomes fatigued, play round the wafer, and this colour will be the complementary colour of the wafer. If the wafer is red, the ring will be green; if the wafer is orange, the ring will be blue. These rings of colour are termed *accidental.*

As a general rule, colours will appear to the best advantage when they are complementary to each other. In arranging flowers in a garden or bouquet, blue will look best with orange, and violet next to yellow. White, red, and pink, should be surrounded with green leaves or white flowers. When colours are grouped which are not complementary, the effect on the eye is similar to that on the ear from a musical instrument out of tune.

The Rainbow.—The rainbow is a brilliantly coloured arc of seven different colours, generally exhibited upon the clouds opposite the sun during the

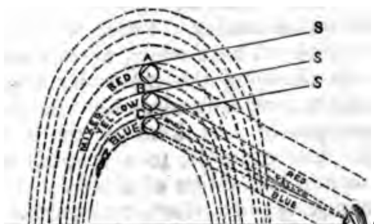


Fig. 60.

occurrence of rain and sunshine. The rainbow is produced by the refraction and reflection of the solar rays in drops of falling rain. A rainbow may also be formed by the sun shining on drops of water falling from a fountain or waterfall. The rays of light proceeding from the sun fall upon the spherical drops of rain, undergo refraction, are internally reflected, and then emerge into the atmosphere and undergo a second refraction. The result is that the emergent rays are resolved into the prismatic colours, which, reaching the eye from different drops, give rise to the colours which are observed. Let A B C (*Fig.* 60) be three drops of rain, S A, S B, S C three rays from the sun. The ray S A, by refraction, is divided into three

colours,—the blue and yellow are bent above the eye at D, and the red enters it. The ray S B is divided into three colours,—the blue is bent above, and the red falls below the eye, while the yellow enters it. The ray S C is also divided into three colours,—the blue, which is bent most, enters the eye, and the other two fall below it. Thus the eye sees the blue at C, and of all drops in the position of C, the yellow at B, and the red at A; and the same may also be inferred respecting the other four colours of the spectrum: each drop sends a different colour to the eye, and thus the eye sees a rainbow.

It is only at certain angles that the rays emerge with sufficient intensity to affect the eye with colours. Hence it is that the coloured drops are arranged symmetrically about a line drawn through the sun and the eye of an observer. The centre of the bow is in this line, and as the sun declines towards the horizon the bow rises, and at sunset it is a semicircle.

We have seen that the rays of light differ greatly in refrangibility. Only a single and different coloured ray from each drop will reach the eye of the spectator; but as in a shower there is a succession of drops in all positions relative to the eye, the eye is enabled to receive the different coloured rays refracted at different inclinations. Two rainbows are not unfrequently observed at the same time, the one exterior and less strongly marked than the other. The inner arch, which is the brightest, is the *primary bow;* the outer arch, in which the colours are reversed, is called the *secondary bow.* This bow is formed by light which enters the drops, and being refracted, is twice internally reflected, and then emerges, being again refracted. As no two persons can occupy exactly the same position, it is quite clear that no two can see the same colour

reflected from the same drop, and consequently no two persons can see the same rainbow.

The beautiful crimson colour of the clouds after sunset is mainly due to the fact that the red rays of solar light are less refrangible than any of the other colours, and in consequence of this they are not bent out of their course like the blue and yellow, and are therefore the last to disappear; and for the same reason they are the first to appear in the morning, and give the clouds their crimson colour.

Chromatic Aberration. Achromatism. — Lenses, as alluded to so far, have this defect,—they give a rim of colour round the image of the object. This may be seen by looking at a gas flame through an ordinary convex lens—the more convex it is the plainer will be the coloured fringe. We have seen that lenses may be viewed as compounded of prisms, and they, like prisms, *disperse* as well as refract white light. As the primary colours are varyingly refrangible, they focus differently, and seven coloured images are produced. The centres of the seven agree, giving the proper mixture for white light; but the more refrangible colours extend further at the edges, giving the coloured fringe. This is called chromatic aberration. An arrangement of prisms or lenses with different refracting angles, and formed of substances with varying dispersive powers, will enable us to overcome this great defect, and will produce clearly defined images with an entire absence of colour. Lenses made on this principle are called achromatic lenses, for they refract the light without decomposing it. To Dolland, a London optician, this great improvement in lenses is due.

An achromatic lens consists of two or more lenses made of different kinds of glass. The combination usually consists of two lenses—a double convex, made

of crown glass; and a concavo-convex, made of flint glass.

By achromatic lenses refraction is produced without any appreciable dispersion. The dispersive power of flint glass is almost double that of crown glass, so that by suitably lessening the refracting angle of the flint glass—for the dispersion diminishes with the refracting angle—the dispersed rays will again be combined into white light. Refraction does not vary according to variation in dispersive power, so that refraction remains, whilst the dispersion is removed. A set of six lenses may be purchased at a small cost, like those in *Fig.* 50. No. 1 should be of crown glass, No. 6 of flint glass. Then with No. 1 chromatic aberration may be shown as mentioned above, and by placing No. 6 with it, the coloured fringe will be found to be removed. All good optical instruments are now fitted with achromatic lenses.

Fig. 61.

Undulatory Theory.—The wave theory of accounting for the phenomena of light has already been mentioned. It is important to be able to apply it to the explanation of colours, of reflection and refraction, &c. And first, we understand a ray of light to originate from the particles of the luminous body being in violent agitation. This motion is imparted to the particles of ether next to the luminous body, and by these particles of ether the motion is given up to the next, exactly as in the case of sound when travelling by the denser medium, air, until the vibrating ether enters the pupil of the eye and sets the nerve fibres of the retina in motion, which by the optic nerve is continued to the brain. Carrying out the analogy between light and sound,—you will remember that sound is more intense according to the

amplitude of the vibration. It is the same with light. Again, the longer the wave the lower the sound. So in light the longest waves give the red colour, whilst a short undulation gives the violet, which corresponds with acute sounds. The length of wave for the red colour is ·0000271 of an inch, for violet ·0000155 of an inch. Here is a marked contrast between light and sound. The waves in the former are extremely short compared with those of the latter.

According to the wave theory certain bodies have the power of reflecting some colours and of absorbing others; that is, they can excite waves of different lengths whilst waves of other lengths are destroyed by them.

White light is a mixture of all lengths of undulations, and a body appears white when it reflects all equally; black when it reflects none. A red body reflects waves of that length which give red light, whilst it extinguishes others. Allow a piece of red paper to reflect light to a sheet of white paper. It will be noticed that the reflected colour is red, and so on with the other colours. Place a piece of red paper in the red of the spectrum; it is a more intense red. Now place it in the blue; the red is almost black, because there is little or no red light to reflect, and blue it absorbs. A transparent substance is so because the wave-motion imparted to it is given up at the opposite side in waves of the same length, whilst an opaque body absorbs or stops all the waves. Place a piece of blue glass before the eye,—blue light only passes the glass, yellow and red are absorbed by it. So with red glass, red rays only pass through, blue and yellow are absorbed.

Frauenhofer's Lines.—In a well-defined solar spectrum there are certain dark lines in the colours, known by the name of Frauenhofer's lines. They

occur in groups of fine lines, and occasionally a thick line occurs: their order and position never change, consequently they offer excellent standards for judging of the amount of refrangibility in the different coloured rays. The greater the magnifying power used in observation of the spectrum, the greater the number of lines seen. Leaving all out but the principal, we find that two well-marked lines occur in the red, and one in each of the other primary colours.

Spectrum Analysis.—These observations have been carried still further, and it has been shown that the vapours of metals, when incandescent, will each, on refraction through a prism, give a peculiar spectrum. For instance, silver subjected to this experiment will give a beautiful green line across the spectrum. Sodium gives one bright yellow bar in the position of that dark Frauenhofer line which is in the yellow of the spectrum, while the remainder of the spectrum is rendered dark by the absorption of the primary colours; and this test for the presence of sodium is so delicate that $\frac{1}{100,000,000}$ of a grain will show the sodium spectrum. Each metal gives its own peculiar lines of varied colours. When two or three metals exist in the same vapour the whole of the lines are shown in the same spectrum, each in its own position, and it is remarkable that these lines of colour never interfere with each other in taking their positions in the spectrum, that is, no two metals give lines on the same part of the spectrum. This wonderful discovery has already been extensively applied by the astronomer and in the chemical laboratory. To detect the lines in the spectrum, an instrument called a spectroscope is necessary, which will be described under the head Optical Instruments.

When an intense light, as the oxyhydrogen or oxy-

calcium flame, is allowed to send a ray through a prism, a beautiful spectrum is obtained without the Frauenhofer lines. In the path of this dispersed ray place the incandescent sodium flame; this is roughly obtained by throwing salt into a vessel containing inflamed spirits; the Frauenhofer line will at once appear in the centre of the yellow. From this we conclude that the sodium flame has the property of absorbing yellow rays, *i. e.*, those of the same colour which it sends out; and further, that incandescent vapours and gases absorb the same coloured rays which they emit.

From this we may draw important conclusions as to the sun's constitution. When we find that in the solar spectrum there are dark lines occupying the places of the bright lines belonging to sodium, hydrogen, &c., we consider that the sun is enveloped in a gaseous atmosphere which contains those substances in an incandescent state. Observations are now being constantly made by spectrum analysis, on the constitution of the heavenly bodies, and new discoveries follow in this untrodden field of science.

Interference.—The reader is referred to the remarks made under this head in Acoustics.

Every undulation consists of a rise above, and a corresponding fall below, a horizontal line drawn from the beginning to the end of the wave. Now, if we conceive that a second wave overtakes a first one, so that the rise of the two waves shall occur at the same instant, there will be an increased wave, the rise will be higher. Now allow the second wave to overtake the first, so that the rise of one shall happen at the same moment as the fall of the other. Then the wave will be completely destroyed.

Again: any reflecting substance which is extremely

thin, as, for instance, a soap-bubble, has wa es of light proceeding from the outer surface which suffer interference from the rays following them from the inner surface of the substance. In the case of waves of ether, when they are destroyed, the light is also destroyed. This is what is known as interference of light. By experiment it may be shown thus,—

Into two holes near together in the shutter of a dark room put two pieces of red glass: two red cones of light will fall with their bases to the opposite side of the room, and be received on a white screen. The cones as they widen out interfere with each other, and the screen would receive the bases as in *Fig.* 62.

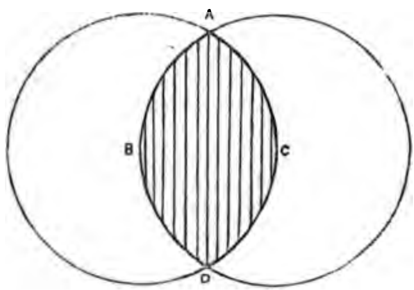


Fig. 62.

The part A B C D would be found to contain alternate black and red bars; the red intense, the black produced by interference. Violet glasses would give violet cones and dark and violet bands, and so on with the other colours. There would be this difference, that as the colours are varyingly refrangible, the bands would vary in width. It is not difficult to see that, if white light were used, each separate colour produces its own coloured and dark bands; and these

being superimposed, and not of the same width, the dark lines of one colour are illuminated by the coloured bands of the other, and alternate bands of varied colour are thus produced.

Interference may also be readily shown to take place by reflection. It is only necessary to place two mirrors at a very obtuse angle, concentrate light upon them both, and receive the reflection on a screen, when the fringes of colour will appear.

EXAMPLES OF INTERFERENCE BY REFLECTION :—

1. Newton's rings—2 plates of glass, one slightly convex, compressed together will give rings of colour, from the extreme thinness of the film of air between the plates.

2. A few drops of oil on water will show colours by interference. The colours also are sometimes seen on stagnant water, caused by oxidizing films of mineral contents of the water.

3. Steel buttons with very fine lines cut across them will give the colours by reflection.

4. Soap-bubbles give colours by reflection also.

EXAMPLES OF INTERFERENCE BY REFRACTION :—

1. Newton's apparatus will show the effects by refraction also.

2. Smoke a piece of glass, and draw fine lines across it with a needle. Look through it at a candle flame, and the colours will be observed.

3. Similar results may be obtained by looking through the barbs of a feather at a light.

4. A crystal of Iceland spar often shows bars of colour, because of the thin layers of spar which are broken away in ledges, and cause interference. Mica will also give them.

Numerous examples may be found by an observing eye amongst the commonest materials.

Diffraction.—This is a change which light suffers on passing the edge of an opaque substance, or in traversing a very small opening. The light appears to bend out of its course slightly in passing the obstruction, and then to give effects very closely allied to those we find in interference. In short, the light and dark bands are produced with homogeneous light, and with white light the coloured fringes; small opaque bodies, as globules of vapour in the atmosphere, will give similar effects. Haloes around the sun and moon are due to this cause. A beautiful effect, due to diffraction, is obtained by sprinkling lycopodium powder on a glass plate, and then looking through the plate at a flame.

Polarization of Light.—We now approach what is confessedly a very difficult subject to understand. Suppose we have two pieces of cardboard, one rather shorter than the other, and that we insert the shorter one into a slit cut in the longer, so that they are in planes at right angles to each other, as in *Fig.* 63.

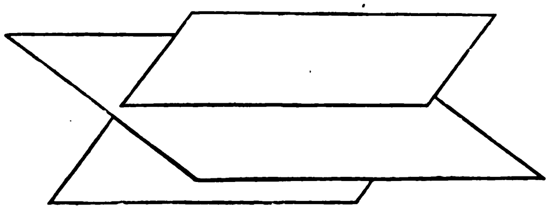


Fig. 63.

Then these would represent a ray of ordinary light, which must be looked upon as compounded of two rays in planes at right angles to each other. Now,

if by any process or under any circumstances this compound ray gets split up into its component parts, then we can imagine the two rays proceeding on their journey independent of each other. In this state no difference would be observed without special means, to be mentioned hereafter, of observing them. Both the rays are said to be polarized.

Polarization is thus defined by Professor Whewell:— "Opposite properties in opposite directions so exactly equal as to be capable of accurately neutralizing one another."

Light may be polarized by reflection, and by single and double refraction.

FIRST, BY REFLECTION.

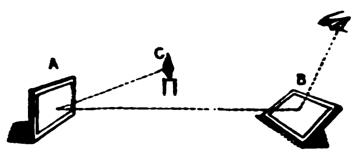


Fig. 64.

Let C A (*Fig.* 64) represent a ray of light falling upon the mirror A, it is reflected to mirror B; and if this were in a perpendicular position, the ray would be reflected from the second mirror. It is, however, at the polarizing angle of glass, viz., 56°, and it will give no reflection. From the first mirror A there is a reflected ray, but it is polarized, that is, it consists of light in one plane only, and when this strikes the second mirror at the polarizing angle 50° 45′, it is not reflected at all. Light is much more commonly polarized than is generally supposed. The surface of smooth water, slates on the roofs of houses, especially when wet, polarize light by reflection.

To ascertain if it be so, it is only necessary to examine it by an analyzer, as it is called. In two positions the analyzer will reflect no light if the observer is experimenting on light already polarized.

SECOND, BY SINGLE REFRACTION. If a ray of light passes through a series of glass plates, it is polarized by refraction. The incident angle at which the ray must fall to produce polarization varies according to the number of plates. For 20 plates this angle is about 65°.

A smaller number of plates will partially polarize the light, but the effect of these plates is never very satisfactory.

THIRD, BY DOUBLE REFRACTION.

Double Refraction is a property which some bodies possess of causing a ray of light, in passing through them, to undergo two refractions; that is, a single ray is divided into two rays. Many crystals have this power, but Iceland spar possesses it in a remarkable degree. That the phenomenon of double refraction is due entirely to the molecular structure of the medium through which the light passes, is proved by taking a cube of regularly annealed glass, which produces but one refracted ray; but on heating the glass and subjecting it to pressure, or to rapid cooling, a change is effected in the molecular arrangement of the parts, and double refraction takes place.

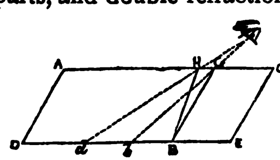


Fig. 65.

In *Fig.* 65 let A D E C represent the section of

a crystal of Iceland spar, and let a ray of light proceed from letter B; it will be doubly refracted; the ordinary ray will pass to G, and an extraordinary ray will pass to H. The eye will see the letter B in positions *b* and *d*, the ordinary refraction producing *b*, the extraordinary *d*. The ordinary laws of refraction do not apply to the latter ray.

If we look at a small object, such as a letter, through a plate of glass, it appears single, but if a plate of Iceland spar be substituted a double letter will be seen.

Turn the crystal round, and the two images will be seen apart, the extraordinary image revolving round the ordinary. Both these rays are polarized in planes at right angles to each other. For the compound ray in its course meets with varying resistance in its two planes from the structure of the crystal, and as this is the same as elasticity, and velocity depends upon elasticity, therefore the rays cannot emerge together.

A crystal of tourmaline cut in two, and the two parts placed at right angles with each other, will allow no light to pass through them, although separately they are transparent. One plate will act as polarizer, and the other as analyzer.

To understand this on the theory already advanced,

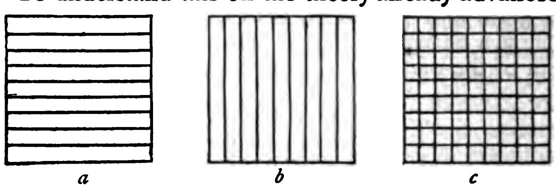


Fig. 66.

let *a*, *Fig.* 66, represent the tourmaline polarizer, along which in the direction of the axis we will suppose lines to be drawn; these will represent the obstruction

which prevents the passage of light polarized in one plane; *b* is the same placed crosswise to represent the hindrance to the passage of the light polarized in a plane at right angles to the first; and *c* shows clearly that all light will be prevented by placing the crystals with their axes across each other. A small instrument called the *Tourmaline Pincette* may be used for demonstrating the above. It consists of a bent wire in the form of pincers, in the two ends of which are placed small discs of wood, moveable; and in the centres of the discs are placed the tourmaline crystals. Suppose the eye to be placed so as to observe light passing through, then allow either of the two to remain at rest as a polarizer, and turn the other—the analyzer—round slowly. It will be found that in two positions light is transmitted, and in other two they are opaque. Let us begin with a clear transmission of light at 0°, then this will lessen, and it will gradually be reduced up to 90°, when no light will pass. Again it will become gradually lighter up to 180°, then dark again at 270°, and, of course, again clear at 360°. From the preceding explanation this will be understood by the careful reader. Noremberg's Polariscope is the most simple and complete apparatus for experiments with polarized light. It consists of a disc of wood with a circular mirror fitted in it; from the disc rise two supports, in the lower part of which is a reflecting glass plate, hung as a common swing looking-glass. There is at the side a graduated circle, by which to set the glass at any desired angle. At the top of the supports a wooden ring is placed in which may be put a Nicol's prism, or a darkened reflector may be supported at an angle, and made to revolve. It is used in the following manner:—A ray of light strikes the reflecting glass at

the polarizing angle. One part of the ray is thrown off polarized, while the other polarized ray passes through the glass to the mirror. From this it is reflected vertically to the top of the framework, where the analyzer may be brought to bear upon it. This apparatus will readily show the alternate light and dark positions, as mentioned under the tourmaline pincette.

Amongst the many most interesting and instructive experiments on light and colours which may be performed by means of the polariscope, the following is mentioned as an illustration :—

Place a very thin plate of selenite or mica on a support between the unsilvered mirror and the analyzer, so that the polarized ray, in rising to the top, must pass through the crystalline film. We will suppose this to be of a monochromatic colour, say red; then, as the analyzer is turned round, the colour will disappear, and at 45° there will be no light transmitted; then, on turning again, the complementary colour green will show up to 90°, and again at 135° all will be dark; turn further, and red will again appear at 180°; and so on round the whole circle.

Light is also polarized by reflection from many substances, such as glass, water, ebony, air, mother-of-pearl, and the surfaces of crystals, provided that the light fall at a certain angle peculiar to each substance; and this angle is called the polarizing angle.

The best polarizer is a Nicol's prism. *Fig.* 67.

The refracting index of the ordinary ray is				1·654
"	"	"	extraordinary ray is	1·483
"	"	"	Canada balsam is	1·549

A crystal of Iceland spar is cut across from obtuse angle A to obtuse angle B, the two half-crystals are then cemented together with Canada balsam. The ordinary ray is so refracted by structure of the crystal

together with the refraction caused by the Canada balsam as to come out at the side at D, while the extraordinary ray pursues its course and emerges at F, both rays being polarized.

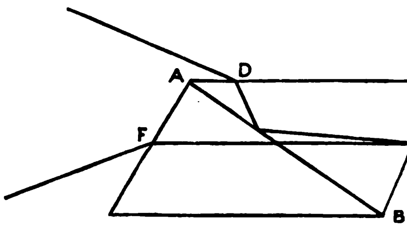


Fig. 67.

OPTICAL INSTRUMENTS.

Telescopes are instruments for viewing distant objects. They may be divided into two kinds—*refracting telescopes* and *reflecting telescopes*. In refracting telescopes a lens, usually called the object-glass, is employed to form an image. In reflecting telescopes a mirror or speculum is used for the same purpose. In both, the image formed is seen by a lens or a combination of lenses called the eyepiece. The method of arranging these parts, together with the auxiliary pieces, determines the particular kind of telescope.

An astronomical telescope consists essentially of two convex lenses—the object-glass and the eye-glass, or of one concave mirror and the eye-glass. An inverted image of a star is produced by the object-glass, or by the mirror, and magnified by the eye-glass. *Fig.* 68 represents this arrangement.

The rays of light being parallel—for they come from great distances—pass through lens N and form an

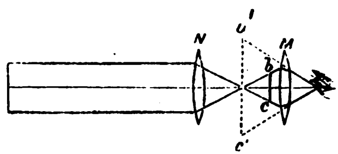


Fig. 68.

inverted image, *b c*, between the eye-glass and its principal focus. The rays passing through the lens M are refracted, and the eye sees the image much magnified at *b′ c′*. In a good telescope the magnifying power does not exceed 1,000 or 1,200. The image is inverted, but of course that is of no importance in viewing the heavenly bodies.

A terrestrial telescope differs from an astronomical telescope in having two additional convex lenses, which together constitute what is called an erecting piece, which enables the observer to see images erect instead of inverted.

The Galilean Telescope is so called from its inventor Galileo. It is, in fact, a common opera-

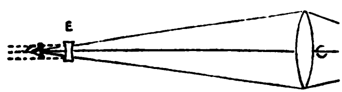


Fig. 69.

glass, which consists of a convex object-glass and a double concave eye-glass. *Fig.* 69 represents this kind of telescope, where O is a convex object-glass, in the focus of which an inverted image of the object would be formed were it not for the double concave lens E. The converging rays of light are caused to diverge by falling on this lens, enter the eye much less convergent, and form an erect image of the object.

So far we have assumed that the eye-glass consists of one lens, for simplicity of illustration; but it must be borne in mind that in good instruments both spherical and chromatic aberration require correction, and that in terrestrial telescopes an erecting combination is also necessary. The fact is, there are many arrangements of lenses in eyepieces, according to the results aimed at or the opinions of opticians. Campani's, Ramsden's, and Dolland's are the most noted.

A reflecting Telescope is one in which the image of a distant object is formed by means of a polished metal reflector or speculum, which image is then viewed with an eye-glass. The eyepiece may either be a single lens or a combination of lenses. One of these telescopes was constructed by Newton (*Fig.* 70). It consists of a concave speculum, A A, placed at one end of the tube, and a small plane mirror, C D, placed

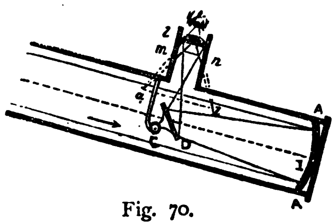


Fig. 70.

obliquely to the axis of the tube. The image of a distant object formed by the speculum A A is reflected by the mirror C D to a point, *m n*, on the side of the tube, and is there seen through an eyepiece, *l*, which is made of two plano-convex lenses. Large reflecting telescopes are now constructed without the small plane mirror C D. This is accomplished by means

of a small rectangular prism, which takes the place of the speculum. The arrangement of the eyepiece is the same.

The Gregorian and Cassegrainian Telescopes.—These are the most prevalent forms of the reflecting telescope. The Gregorian will be understood from *Fig.* 71. The rays enter parallel, strike the mirror at A,* and form an image at B. This image is reflected from a small mirror, C, to the opening in

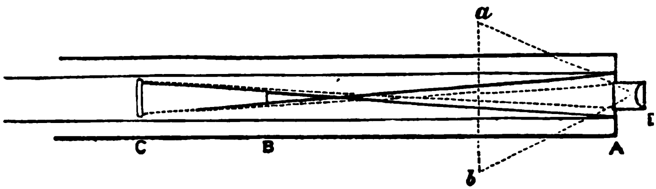


Fig. 71.

A, where it is viewed by the eyepiece D, and so enlarged into the image *a b*. Much light is lost by this instrument in the double reflection.

The Cassegrainian differs from it in having the large mirror curved so as to throw the image to the side of the tube, where it is viewed with lenses. Very large telescopes of this kind are often arranged so that the astronomer can ascend and use the eyepiece in the upper end of the tube; there is then only one reflection, and therefore little loss of light.

A microscope is a modification of a telescope, and is used for viewing near objects. Microscopes are either simple or compound. The simple microscope consists of a double convex lens of short focal distance. It is usually set in a frame of horn or

* The interior of end A is one large mirror with an aperture in the middle for the eyepiece, and this mirror is spherical.

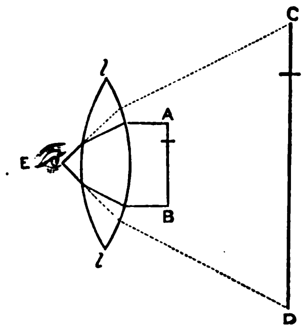


Fig. 72.

metal, and held in the hand. It is, in fact, a simple magnifying glass. *Fig.* 72 represents the magnifying principle of the microscope. An eye at E would see the cross A B under the visual angle A E B; but when the lens *l l* is interposed, it is seen under the visual angle C E D, and therefore appears much enlarged, as shown at C D.*

The compound microscope consists essentially of a double convex lens called the *object lens*, and a second double convex lens called the *eye-glass*. *Fig.* 73 shows a section of this instrument. The object to be observed is placed at *a*, between two plates of glass, on a support. Over this is a tube, in which are placed the two lenses,—the object lens, *l*, at the lower end, and the eye-glass, L, at its upper extremity. The object, *a*, being placed a little beyond the principal focus of the object-glass, this lens produces a real image, *b c*, which is inverted. The object-glass is so placed that its principal focus is a little beyond the image *b c*, and between the eye-glass and its principal

* Lines E C and E D should be perfectly straight.

focus. This lens then acts as a simple microscope, and magnifies the image as if it were seen at C D. The magnifying power of any optical instrument is the ratio of the magnitude of the image to that of the object. In a compound microscope we take the product of the magnifying powers of the object-glass and eye-glass to represent the magnifying power; thus, if object-glass magnifies 20 times and eyepiece 50, we have a power of 1,000. To obtain clear images the magnifying power ought not to exceed 500 or 600 diameters, which gives from 250,000 to 360,000 as the superficial increase. The power is greatly increased by combining several lenses. A second lens is often added to the eye-glass, for the purpose of remedying the defect arising from spherical aberration, and all the lenses are achromatic. The object, when transparent, is illuminated by a mirror, M, which concentrates the rays upon it. When the object is opaque it is illuminated by a lens which projects from the side and concentrates the rays upon it.

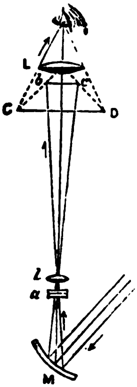


Fig. 73.

Camera Lucida.—Invented by Woollaston in 1804. A four-sided prism is used. A is a right angle, C is 135°, B and D $67\frac{1}{2}°$ each. The rays from an object pass in at *r*, are totally reflected at S, and *again at o*, passing to the eye, which sees an image at E, where the hand may be employed in drawing a picture of the object. This instrument is used by architects for making sketches of buildings.

A Camera obscura, or dark chamber, may be constructed by using an ordinary box for a dark room.

At an opening in one end is placed a convex lens, through which the rays from the object pass. They are received on a mirror placed at an angle of 45° at the opposite end of the box, and from this reflected upwards, at right angles. At the top of the box is placed a ground glass screen on which a good image

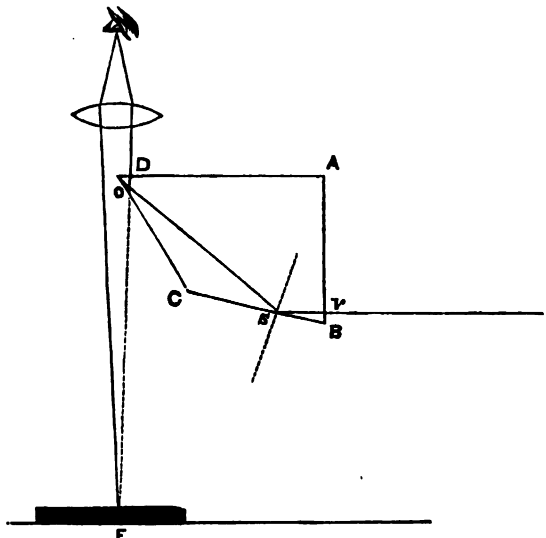


Fig. 74.

of the object in front of the lens is formed. With tracing paper a drawing may be easily made on the ground glass screen.

Sometimes a small circular dark room is used with a mirror at the top. There is a lens below on which

the rays from the mirror fall; they are refracted and focussed on a white table in the centre of the apartment.

Photographic Camera.—From the camera obscura it is but a short step to the camera used by the photographer. If we imagine that a substance sensitive to light takes the place of the ground glass screen, we at once see that the object will be reproduced on the sensitive plate. This is now done on metal, glass, or paper. The photographer uses a modified form of the camera obscura. There is a brass tube in front of a box, which consists of two parts, arranged to pass one within the other. In the brass tube is a condensing lens, and at the back of the box there is a groove, in which a ground glass screen is placed and may be removed. When the object is clearly focussed on the screen, it is removed and the sensitized plate is put in the groove. The picture is instantly formed by the action of light on the chemically prepared plate; it only remains to be developed further and fixed by other chemical processes.

The Spectroscope.—On a stand is placed a telescope, with object-glass covered by a cap of metal in which is a narrow slit. The light passes through this slit to the centre of the stand, on which a prism is fixed. This produces the spectrum, which is viewed by another telescope conveniently placed on the same stand. In front of the slit is a non-luminous flame, such as a Bunsen's lamp, and in this is placed a loop of platinum wire with the substance to be experimented upon. The minutest quantity of any metal will give its characteristic spectrum.

The Magic Lantern.—A is a silvered reflector; B, the light; C and D, lenses for concentrating the rays of light, and powerfully illuminating the picture; E, the picture, which must be inverted; F, a diverg-

ing meniscus; G, a converging meniscus, the uses of which are evident from the courses of the rays; H,

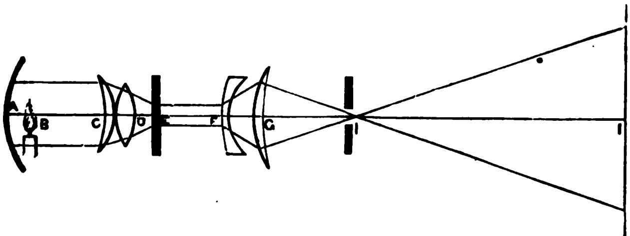


Fig. 75.

the small opening in the front of the lanterns from which the light emerges. Here we see why the picture must be inverted, for at this opening the rays cross, and by inverting the picture we obtain an upright image on the screen I.

Lenses C D F and G may be of different arrangement. It is not uncommon to have C and D large plano-convex lenses, and F and G smaller ones of the same kind.

List of Necessary Apparatus.

	£	s.	d.
Ritchie's photometer (easily constructed from description in the body of this work)	0	5	0
Rumford's photometer (easily constructed from description given)	0	5	0
Set of lenses	1	1	0
Concave and convex mirrors	0	10	0
Ground glass plate in frame, with black and white screens	0	5	0
Glass prisms (these may often be purchased from china dealers for a trifle)	0	2	0

	£	s.	d.
Colour top, to show effect of combining colours (easily made)	0	5	0
Plates of different coloured glass . . .	0	2	6
Complementary prisms of flint and crown glass	0	10	0
Two rhombs of Iceland spar	0	4	0
Nicol's prism	0	7	6
Two plane mirrors	0	5	0
Kaleidoscope	0	1	0
Zoetrope to illustrate persistence . .	0	5	0
Stereoscope, with geometrical slides . .	0	5	0
Newton's disc for combination of colours (easily made, and may be made to revolve rapidly by the same wheel as that used for the syren)	0	7	6

List of Additional Apparatus.

	£	s.	d.
Mounted prism	0	12	6
Prismatic bottle	0	5	0
Camera obscura (easily constructed) . .	0	7	6
Interference prism	0	5	0
Apparatus for Newton's rings	0	10	0
Tourmaline pincette	0	10	0
Noremberg's polariscope	2	0	0
Plates of quartz, aragonite, selenite, nitre, &c., each	0	5	0
Apparatus to show laws of reflection and refraction	0	18	0
Lime-light apparatus	8	0	0
Powell's wave apparatus	3	13	6
Spectroscope (complete)	5	5	0
Magic lantern	3	3	0
Compound microscope, achromatic . .	3	0	0
Opera-glass	0	10	0
Telescope, achromatic	0	10	0

HEAT.

Heat is known only by its effects on matter. It makes water boil, iron by its means becomes red-hot, and so on. In ordinary language the term heat is used to express the sensation of warmth, and absence of heat constitutes cold.

Two theories have been advanced to explain the phenomena of heat.

The first theory supposes heat to be an elastic fluid without weight, enveloping and permeating all bodies, and capable of passing freely from one body to another. The particles of this fluid repel each other, and are attracted by the particles of other bodies. This is called *the emission theory*. According to the second theory, heat consists of the vibratory motion of the particles of bodies, which motion is transmitted from one body to another through an elastic fluid, called ether, in a manner precisely the same as sound is transmitted through the air. The warmest bodies are those in which the vibrations are most rapid. This is *the undulatory theory of heat*. According to the first theory, a body cools by losing a portion of the fluid; according to the second theory, in cooling, its vibratory motion becomes less rapid.

All bodies expand by heat. In a solid body there is expansion on the application of heat. The heat is converted into motion, the solid particles may be looked upon as endeavouring to overcome external pressure, and the force of cohesion which holds them together. The result of the continued application of heat is expansion, which goes on until the solid is converted into a liquid; now the force of cohesion is slight, and the application of heat will have a greater

effect in expanding the liquid, for there is only external pressure of the atmosphere to overcome. The gaseous state will follow, where cohesion is almost nil, and pressure alone the counteracting force. In short, then, solids expand with heat slightly, liquids to a much greater degree; gases are extremely dilatable.

There are three kinds of expansion,—linear expansion or dilatation, superficial expansion, and cubical expansion or increase of volume.

Linear and Superficial Expansion.—Expansion of Volume.—If we wish to compare the rate of linear dilatation of different bodies, we must take for a term of comparison the expansion experienced by a unit of length of each body when heated from 32° to 33° F., and this is called the co-efficient of linear expansion. The co-efficients of linear expansion on many bodies were determined by Lavoisier in the following way:—The substance to be experimented on was reduced to the form of a uniform bar. It was then exposed for some time to the temperature of melting ice, and its exact length measured. The bar was then exposed to boiling water, and its exact length again measured. The increased length, divided by 180°, gave the increase in length of the whole bar for 1° F. This result, divided by the length of the bar at 32° F., gave the linear expansion of a unit of length for an increase of temperature of 1° F., that is *the co-efficient of linear expansion.*

The co-efficient of superficial expansion is, as the term implies, the increase in surface of a square unit, for a rise of 1° F. in temperature. It may be obtained by doubling the co-efficient of linear expansion. The reason of this is explained in the next paragraph.

The co-efficient of expansion in volume is the increase which a cubic unit of the substance undergoes when its temperature is raised 1° F. This co-efficient may be found experimentally, or by multiplying its co-efficient of linear dilatation by 3. For although the co-efficients vary with different bodies, for the same body the co-efficient of cubical expansion is three times that of linear expansion.

Suppose a rectangular bar, whose length, breadth, and thickness are $a\ b\ c$, its contents will bear a certain ratio to a^3. If it be expanded it will bear the same ratio to a cube of the side corresponding to a, for all parts expand proportionally. Hence, if h be the linear dilatation of a, the new length will be $a + h$, and the ratio of the contents or volume will be $a^3 : (a+h)^3$. The measure of linear dilatation is then $\frac{(a + h) - a}{a}$, and of cubical expansion $\frac{(a + h)^3 - a^3}{a^3}$; the first equal to $\frac{h}{a}$, and the second to $\frac{3a^2h + 3ah^2 + h^3}{a^3}$ or to $\frac{3h}{a} + \frac{3h^2}{a^2} + \frac{h^3}{a^3}$. In all cases of solid expansion, $\frac{h}{a}$, the linear dilatation, is a very small fraction. Thus, for Falmouth tin, heated from 32° F. to 212° F., it is only $\frac{1}{462}$. The ratio of cubical expansion to linear dilatation, which is $\left(\frac{3h}{a} + \frac{3h^2}{a^2} + \frac{h^3}{a^3}\right) \div \frac{h}{a}$, or $3 + 3\frac{h}{a} + \frac{h^2}{a^2}$, differs very little from 3, and we may safely take this rule, when not requiring an exactness within $\frac{1}{150}$ of the whole quantity measured, that the cubical expansion may be found by trebling the linear dilatation.

The co-efficients of linear expansion, as given by Professor Tyndall, are for—

	Inches.
Platinum	0·0000088
Glass	0·0000086
Iron	0·0000123
Silver	0·0000191
Gold	0·0000146
Copper	0·000017
Lead	0·000029
Tin	0·000023
Zinc	0·000029
Water	0·00046
Alcohol	0·00116
Mercury	0·000154

For the surperficial expansion multiply by 2; for the cubical, by 3.

Note carefully the co-efficients of platinum and glass. They are nearly alike. Many instruments used in physical science require platinum wire to be fused into glass. This may be done, because they expand and contract alike; therefore, in contracting, the glass does not leave the platinum.

The co-efficients of expansion of gases are given as follows:—

Hydrogen . . .	0·00366
Air	0·00365
Carbonic oxide . . .	0·00367
Carbonic acid . .	0·00371
Sulphurous acid . .	0·00390

From consulting this table, the student will notice that carbonic acid, and more notably sulphurous acid, differ from the other gases in their co-efficients. They are, in fact, imperfect gases; they are in an intermediate state between gases and liquids, and are with comparative ease compressed into liquids. Gaseous

bodies expand equally for equal increments of temperature, with slight exceptions. 1,000 parts of air at 32° F. become 1,375 at 212° F., and the same expansion is experienced by other aëriform bodies. The ratio of the expansion of gases has recently been corrected by Rudberg, and, according to his investigation, one volume of gas at 32° F. becomes 1·365 at 212° F.

To find the increment of volume for 1° F., we have only to divide the fraction $\frac{365}{1000}$ by 180, which gives $\frac{365}{180000}$, or $\frac{1}{493}$.

The increase of volume, therefore, which any gas or vapour undergoes when the temperature is raised one degree is the 493rd of the volume which it would have if reduced to the temperature of 32°. It follows from this that if air be raised from the freezing point to 493°, it will double its volume. (*Exercise V.*)

Experiments and Examples of Expansion. —Solids.—A pyrometer is an instrument for showing the expansion of metal bars. In *Fig.* 76 a rod, B, is

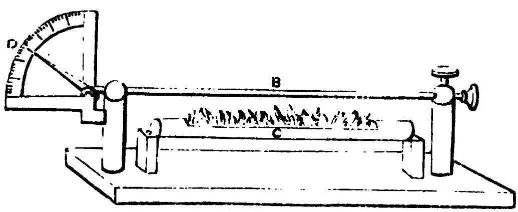


Fig. 76.

subjected to heat from burning alcohol in a vessel, C, and at the end of the rod is an arrangement by which, on a graduated quadrant, D, the dilatation is shown. A Gravesande ring is of exactly sufficient size to allow a cold brass ball to pass through it. When the ball is heated it will not pass through the ring. The pyro-

meter shows the contraction on cooling very clearly; but the power of the contractive force, and therefore of the expansive force, for they are alike, may be shown by an apparatus arranged as in *Fig.* 77, so that when

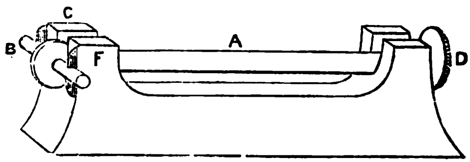


Fig. 77.

bar A has been heated intensely and placed in its position with an iron cross bar, B, to prevent contraction, and by means of screw D this bar is brought firmly against the pillars G and F, it will be found that, on cooling, the cross bar will be broken by the contraction of bar A. Heavy palisades are sometimes firmly embedded in stonework by means of lead, with, as a sure result, the splitting up of the stonework by the expansion of the metal in hot weather, and especially if the stonework is not very strong.

This dilatation and contraction is taken advantage of, or allowed for, by the mechanic in construction; for example, in fixing the iron rim of a wheel upon the wood, in rails of railways, where, it may be noticed, a small space is always left between the rails to allow expansion. The walls of a building when leaning may be brought into position by the alternate heating and cooling of iron bars that are firmly clamped on the outside, and pass through the building. A moulder, in preparing to model a wheel, makes the mould a little larger than the wheel, because he knows the hot metal will contract on cooling. Many other illustrations will occur to an observant student.

Liquids.—The apparatus for measuring the expansion of liquids is too elaborate for these pages; but the dilatation is commonly noticed in mercury and alcohol thermometers, and may be readily shown by placing water in a Florence flask, through the cork of which is passed a glass tube; colour the water with litmus or sulphate of indigo, apply heat to the bottom of the flask, and the water will be seen to rise in the tube four or five inches in a few minutes.

Gases.—Gases expand more than liquids or solids. Take a thermometer bulb, expose it to heat, and then plunge it suddenly, inverted, into water; as it cools, the water will rise in it and nearly fill the bulb. Again, upset a test-tube in a tumbler of water, apply

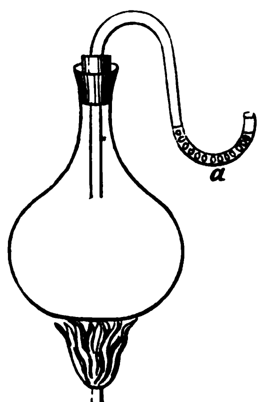


Fig. 78.

heat to part of the tube containing air; it will expand, gradually driving out the water.

A pleasing experiment may be performed with a

Florence flask and a piece of glass tubing, arranged as in *Fig.* 78. Any gas may be put in the flask, and a little water at the bend, *a*, of the tube. Bubbles of gas will pass through the water, and on removing the heat, bubbles of air will repass to fill the partial vacuum caused by contraction of the gas in the flask.

Breguet's Metallic Thermometer.—This instrument is thus constructed. On a wooden disc is placed a graduated dial plate, and upon this a metallic needle moves as an index. The centre of the needle is attached to a spiral ribbon of metal which is preserved in a vertical position by an elbow support rising from the base.

The metallic ribbon is composed of three ribbons rolled together. Silver, the most expansible metal, forms the inner coil. Platinum the outer—and gold is placed between to prevent fracture of the others on expanding and contracting. When the temperature rises the spiral unwinds, because of the silver expanding so much. When temperature falls, of course the reverse is the case, and the amount of rise or fall in temperature is shown by the index on the dial.

The Compensating Pendulum.—The construction of the compensating pendulum depends on the principle of the expansion and contraction of metals. We have seen in *Mechanical Physics*, page 90, that the time of oscillation of a pendulum depends on its length, vibrating faster when shortened and slower when lengthened. If a pendulum were constructed with a single metallic rod, its rate of vibration would be constantly changing with every alteration of temperature. To obviate this, and secure uniformity of vibration, the gridiron pendulum of Harrison was constructed. It consists of five parallel bars of metal, arranged as shown in *Fig.* 79. The bars *a c*, *b d*, and the centre

bar are of steel, and when they expand the effect is to lengthen the pendulum. The centre bar passes through the cross bar *g h*, and is firmly secured to the bar *e f*. The bars shown by the dark lines are of brass, firmly secured to both of the cross pieces. When they expand, the effect is to raise *e f*, and thus shorten the pendulum. If these pieces are properly adjusted, the amount of shortening is exactly equal to the amount of lengthening, and as these balance each other the pendulum remains invariable. There is another form of compensating pendulum, called the MERCURIAL PENDULUM, which consists of a steel frame attached to a cylindrical glass vessel containing mercury. In warm weather the steel frame expands, and thus increases the length of the pendulum and lowers the centre of oscillation; but at the same time the mercury expands and rises upwards, and by a proper adjustment the centre of oscillation rises upward as far as it is carried downward, or in other words, the expansion in both directions is equal, and the vibrations are unaltered.

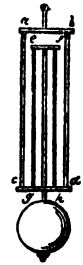


Fig. 79.

The Thermometer.—The thermometer is an instrument used for measuring temperatures. As the temperature increases the thermometer is said to rise, and *vice versa*. A glass tube (*Fig.* 80) of uniform bore is taken, and one end blown into a bulb, in the blow-pipe flame of a lamp, and a small cup is blown in the other end of the tube: this is filled with mercury. The bulb, when nicely formed, is carefully heated over the flame of a spirit lamp. This causes nearly all the air to be expelled, and the remainder on cooling contracts, and part of the mercury fills the vacuum thus produced. The process is repeated, and a fresh

quantity of mercury enters the tube; and so on until the bulb and part of the tube is full. By applying heat so as to cause the mercury to boil, the remainder of the air is driven out. Heat is now applied till the column of mercury rises to the top; it is then hermetically sealed by the blowpipe. The contraction of the mercury leaves a vacuum in the upper part of the tube which is essential to the perfection of the instrument. It has now to be graduated. Two constant points are taken. The temperature of melting ice, or a mixture of ice and water, constitutes the freezing point. The boiling point of water is always constant, regard being had to the height of the barometer when great accuracy is required: this constitutes the boiling point. These points are marked, and the interval divided into degrees: the division is entirely arbitrary. In Europe and America the Centigrade scale is used; in England, the scale known as Fahrenheit's is employed. In the F. thermometer the interval between the freezing and boiling points is divided into 180°; in the Centigrade it is divided into 100°. In F. the temperature of ebullition is expressed at 212°. In Russia, Reaumur's scale is used, which commences at 1°, and the boiling point is at 80°.

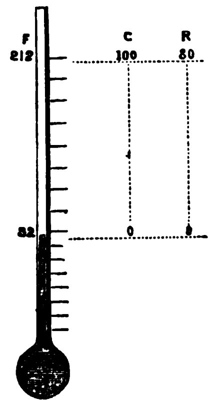


Fig. 80.

A thermometer reveals to us the intensity of heat, not the quantity, for a test-tube of boiling water raises the mercury to the same point as a pailful, although the larger quantity must contain the most heat.

When directions are given to raise the temperature

of a body to 110° it means that heat is to be added sufficient to raise the mercurial column to 110°.

To exchange degrees given in Centigrade, Fahrenheit, or Reaumur, to either of the other two.

C.	F.	R.
5	9	4

RULE.—*Divide by its own number, and multiply by the one to which it is going.*

Note that in leaving F. 32 must be taken away, and in going into F. 32 must be added, for an evident reason. Example :—

80° C. to F. $\frac{80}{5} \times 9 + 32 = 176.$

Ans. 176 F. (*Exercise V.*)

An alcohol thermometer acts by expansion on the application of heat. The alcohol is coloured red with a little cochineal. Alcohol thermometers have to be graduated by experiment with a standard mercurial thermometer, because the alcohol does not expand regularly with an increase of temperature. An alcohol thermometer is more easily constructed than a mercurial thermometer. The glass bulb is heated until a portion of the air is expelled, and then the alcohol passes down the tube from the little cup at the top. As the air in the bulb cools, the pressure of the external air drives down a portion of the alcohol into the bulb. If this be boiled, the vapour of alcohol will expel the remainder of the air, and more alcohol entering, the bulb is filled. The end of the tube is then hermetically sealed. The mercury thermometer is the most useful for many obvious reasons. It expands in proportion to the heat within the ordinary range of a thermometer. Below 36° C. it is irregular in expansion, and at 350° C. mercury boils. Outside these limits it cannot be used. The alcohol thermo-

meter will take its place in the lower temperatures; for the higher, a good thermometer is still a desideratum. Alcohol does not solidify at the greatest known cold.

A differential thermometer consists of two bulbs of thin glass connected by a fine glass tube bent twice at right angles. On the frame is a scale parallel to the horizontal branch of the connecting tube. The o of the scale is at the middle point of the horizontal tube, and the graduations proceed from this in both directions. The bulbs and a large part of the connecting tube are filled with air. There is, however, a small drop of coloured fluid, which separates the air in the two extremities. The index is so constructed that it should be at the o of the scale when the temperature of the two bulbs is the same. When one bulb is heated more than the other, the air expands and drives the index towards the other bulb, until the tension of the air in the two bulbs exactly balance each other. This description applies to Rumford's thermoscope or differential thermometer (*Fig.* 81).

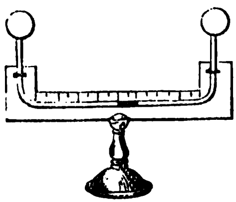


Fig. 81.

Leslie's differential thermometer (*Fig.* 82) differs from the one just described in having bulbs smaller, and containing a column of liquid sufficient to fill the horizontal part and about half the legs. The scales are placed by the sides of the vertical portions of the tube, having their zero points at the middle of the vertical scales, where the columns of liquid finish.

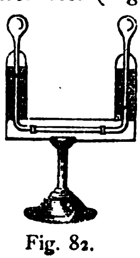


Fig. 82.

The measuring of higher temperatures than those indicated by the mercurial thermometer is of great importance in the arts, but this desirable object has not yet been fully accomplished. The most important thermometers are those of Brogniart and Wedgewood. The former is founded on the principal of the expansion of metals, and the latter on the diminution in the volume of clay at high temperatures, but these instruments are very unreliable, and there is yet wanted some accurate method of measuring temperatures above 600° F. The air thermometer is now always used for measuring high temperatures.

Ebullition, or boiling, is a rapid evaporation, in which the vapour escapes in the form of bubbles. In heating water the first bubbles which rise to the surface are due to the small quantities of air contained in the liquid, which expand and rise to the surface. As the heat is continued, particles of water are converted into vapour and rise through the liquid, becoming condensed by the colder layers of water above. When the whole volume of the liquid is properly heated, the bubbles are no longer condensed, but rise to the surface and escape with a commotion which is called boiling, or ebullition.

The laws of ebullition have been determined, by experiment. They are as follow :—

1. The temperature of ebullition, or boiling point, increases with the pressure.

2. For a given pressure ebullition commences at a given temperature, which varies in different liquids, but which for equal pressures is always the same in the same liquid.

3. Whatever be the intensity of the source of heat, as soon as ebullition commences the temperature of the liquid remains stationary.

The principal causes which influence the boiling points of liquids are the presence of foreign matter, variations of pressure, and the nature of the vessels in which the boiling takes place. Matter in solution generally raises the boiling point of liquids. A solution of salt does not boil so readily as pure water. If, however, the dissolved body is more volatile than water, then the boiling point is lowered. Fatty bodies combined with others raise the boiling point. Hence it is that boiling soup is hotter than boiling water. When the interior of a vessel is rough, the projecting points form centres for the developing of vapour, and the boiling point is lower than when the interior surface is quite smooth. An increase of pressure raises and a diminution of pressure lowers the boiling point. When the pressure is great, the vapour, in order to escape, must have a higher tension, and thus requires a higher temperature. When the pressure is small, the reverse is the case. This principle may be generally stated thus:—A liquid boils when the tension of its vapour equals the pressure which it supports. This is easily illustrated with an air-pump. Under the bell glass of the air-pump place a small saucer nearly filled with water. The water enters into ebullition even at ordinary temperatures when the air is exhausted. This is because of the diminished pressure. If it be desirable to continue the experiment for some time, the vapour must be removed by placing the saucer in a vessel containing strong sulphuric acid. There is no increase of temperature in the water, but, on the contrary, it falls; and by this experiment the water may be actually frozen.

The following experiment illustrates the influence of the boiling point on the pressure. Take a flask with a long neck, fill it half full with boiling water,

and while the steam fills the other part of the flask, cork it tightly, invert it, and a comparative vacuum will be formed; pour cold water on the bottom, and the water in the flask will again begin to boil. On the summit of Mont Blanc water boils at 180·95° F. The lowering of the temperature is about 1° F. for every 590 feet that we ascend. An instrument called a thermo-barometer was used by Wollaston for ascertaining the heights of mountains. It consists of a small metallic vessel for boiling water, to which is attached two or three very delicate and finely graduated thermometers. (*Exercise VI.*)

Papin's Digester is an airtight vessel in which water is raised to a temperature far above the boiling point, and the vapour rises to a tension equal to 4 or 5 atmospheres. This vessel is used on mountains for culinary purposes, the water, when boiling in ordinary open vessels, not being sufficiently heated to soften animal fibre.

Communication of Heat.—Heat may be communicated in three ways—by conduction, by convection, and by radiation. Conductibility is that property of bodies by virtue of which they transmit heat. Those which transmit heat readily are called good conductors; those which do not transmit heat so readily are known as bad conductors. Ingenhouse showed that solid bodies possessed different degrees of conductibility by coating different rods of metal, marble, wood, and glass, with soft wax that would melt at 140° F. These rods were placed in tubes with their open ends outward, the remaining portion of the tubes being immersed in a vessel with boiling water. Upon some of the rods the wax melted rapidly; upon some, more slowly; and on others, not at all. If equal cubes of ivory, marble, glass, and the metals be heated by the same source, and

thermometers placed on these cubes, we shall find the thermometers on the metals will rise first, and those on the ivory and glass last. In these last two experiments the student must remember that the specific heat of each material must also be considered, as one substance will require much more heat to raise its temperature to a certain standard than is wanted by another substance. As a general rule, the most dense bodies conduct heat best. Spongy, light bodies, such as wool, silk, cotton, fur, and eider down, are bad conductors. This explains their use as articles of clothing in winter. We experience the sensation of warmth in using them because they prevent the escape of the animal heat already possessed, and not because they add to that heat. This power of preventing the transmission of heat seems owing to the air they enclose, for on twisting these bodies their conducting power is greatly increased. Solids conduct heat much more readily than liquids. The rapidity with which silver conducts heat may be illustrated by wrapping a piece of muslin round a tablespoon filled with water. If the spoon be introduced into the flame of a candle or lamp the water will boil without burning the muslin. Many examples may be observed in nature,—plumage for the bird, wool for the animal, clothing for man, and snow in winter for the soil. Air is a bad conductor of heat, hence double windows, by interposing a non-conducting layer of air, keep a room much warmer. Glass and china vessels, when hot water is suddenly poured into them, are often broken; they are bad conductors; the part heated expands, and as the other parts do not, there is a fracture. To preserve ice it is necessary to wrap it in wool or place sawdust round it, so that the heat of surrounding bodies may not be conducted to it.

Of course this also serves to keep anything warm. The following table shows the conducting power of different solid bodies :—

	Heat.	Electricity.
Silver	100	100
Copper	74	73
Gold	53	59
Brass	24	22
Tin	15	23
Iron	12	13
Lead	9	11
Platinum	8	10
German silver	6	6
Bismuth	2	2

Convection.—Liquids conduct heat very slowly. If a piece of ice be placed at the bottom of a test-tube of moderate length, and water poured on the top of the ice, the water may be made to boil, without melting the ice, by holding the upper part of the tube in the flame of a lamp. Or if some ether be poured on the surface of a large basin filled with water and inflamed, it will burn for some time without sensibly affecting a thermometer immersed at a small depth below the surface of the water. When a blacksmith plunges a red-hot bar into water, the water becomes boiling hot immediately in contact with the iron bar, but the water not immediately in contact remains at the same temperature as it was before the bar was introduced.

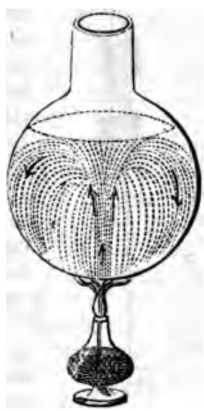


Fig. 83.

If, however, we apply heat to the lower part of a vessel (*Fig.* 83) containing any liquid, it soon shows an increase of temperature. The liquid is heated by the transportation of its particles in quick succession. In this case the particles nearest to the source of heat become heated, and therefore specifically lighter, and ascend through the fluid, to which they impart a portion of their heat, while their place is supplied by another series of particles, which become heated and ascend in like manner; and this succession of rapid changes continues to take place until the whole mass of the fluid is raised to 212° F., the boiling point. These motions may be rendered visible by placing in a Florence flask, heated by a spirit lamp, a few pieces of solid litmus or bran. The coloured fluid or bran will be seen to rise up the centre of the flask and descend down its sides. Faraday's Convection Apparatus will be understood from *Fig.* 84. In both vessels water is placed, mixed with a little bran. In the upper vessel an upward current will be distinctly seen in tube *m*, and at *n* a downward current will be observed; the warm water being lighter, rises, and for the contrary reason the cold water falls. The process of cooling in a liquid is exactly the reverse of that just described. The particles at the surface, by contact with the air, lose a portion of their heat, become heavier, and sink to the bottom; their place is supplied by lighter particles rising from below, and in frosty weather this

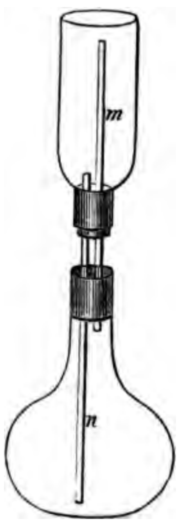


Fig. 84.

circulation goes on until the water acquires its maximum density at 38·75° F., or as it is more commonly given, 4° C. At a few degrees lower ice begins to form at the surface. The general law of expansion by heat and contraction by cold is all but universal; but there are, however, remarkable exceptions to this law, one of which is attended with the most beneficial results. The known exceptions are water and bismuth, which begin to expand at 4° C., and congeal at 0° C. India-rubber is an exception; on the application of heat it contracts, in opposition to the general rule. The expansion of water by cold commences, as we have just stated, a few degrees above the point of congelation, and this expansion increases in an increasing ratio, until the particles assume a definite crystalline form, and a sheet of ice is formed at the surface. If, like oil, mercury, and other liquids, the density of water went on augmenting till it sank to 0° C., it would then suddenly become a solid block of ice, and every living animal within it would perish, and in this climate a river so frozen could never again be liquefied, because the process of thawing would commence at the surface, and the heated and lighter particles would remain there, and prevent the convection of heat to the lower strata. We are acquainted with one of the consequences of this expansion on solidification. Allusion is made to the bursting of water-pipes in the winter season. Leaden pipes from cisterns are filled with the water supply, the volume of the water contracts down to 4°, and then with the weight of water on it from above it begins to expand. The force necessary to burst the pipe is less than that necessary to lift the superincumbent water, so the pipe is burst. For an evident reason we know nothing of the injury to the pipe until a thaw comes on. The conducting power

of gases also varies. Hydrogen has the lowest conducting power, atmospheric air is considerably higher, and carbonic acid gas the highest. The conduction and diffusion of heat by the methods just described is a slow process, and is limited to bodies in immediate contact with each other; but heat may be diffused among bodies not in contact by radiation.

Radiation.—A heated iron ball *in vacuo* emits its heat in all directions; and in air, although a portion of the heat passes off by convection, still we may regard it as propagated through space in straight lines. All bodies radiate heat, but not equally well. The radiation is in proportion to the roughness of the radiating surface. All dull and dark surfaces are, for the most part, good radiators, but bright and polished surfaces are generally bad radiators.

If a metal surface be scratched or made rough, its radiating power is greatly increased. Water in a highly polished metal pot will retain its heat much longer than in one that is black and dull. Leslie procured a cubical vessel of block tin: one side was polished, the second was made rough by scraping, the third he covered with a glass plate, and the fourth he blackened with lamp-black. He then filled the vessel with boiling water, and presented the different sides in succession to a delicate air thermometer, preserving the same distance in each case. He found the polished surface radiated least, and the surface covered with lamp-black radiated most.

The radiation of heat is not confined to incandescent bodies, like the candle or the sun or burning coal; but this radiation of heat goes on at all times, and from all surfaces, whether their temperature be the same or different from that of surrounding objects. The temperature of a body, therefore, falls when it

radiates more heat than it absorbs. Its temperature is uniform when it absorbs and radiates the same amount. When the absorption exceeds the radiation it grows warmer. All bodies tend to a uniform temperature, although this condition is never fully realized. Bodies nearest the outer walls of a room, or another apartment, will be influenced by continually exchanging their heat with the walls and the walls with the atmosphere, and this will exert some influence on the temperature of bodies in the room. Substances which are good radiators are also good absorbers. Experiments with glass will demonstrate that this is the case, and it is these properties of glass that make it so suitable for greenhouse purposes. It absorbs readily the sun's heat, and then radiates it to the interior. The air is much hotter here than outside the structure. Water vapour performs a perfectly analogous part in nature.

The Formation of Dew.—Dew is the moisture of the air condensed by coming in contact with bodies colder than itself. The temperature at which this condensation takes place is indicated on the thermometer as the dew-point. This point is by no means constant, since dew is only deposited when the air is saturated with moisture, and the moisture required for the saturation of air at a high temperature is much greater than at low temperatures. If the saturation is complete, the least fall of temperature is sufficient for the formation of dew; but if the air be dry, then a body must be several degrees colder before moisture is deposited on its surface. Dew may be produced by bringing a tumbler of cold water into a warm room. The sides of the glass cool the surrounding air so that it can no longer retain its moisture, or, in other words, the temperature of the air is reduced below the dew-

point. In the same manner moisture is formed on the windows of a heated room, if the temperature outside is low enough to sufficiently cool the glass. The true theory of dew was first established by Dr. Wells. According to his theory the earth and plants become cooled by the radiation of heat, thus producing a deposit of moisture from the stratum of air in contact with these surfaces. Good radiators are soonest covered with dew, whilst bad radiators have little or no dew deposited on them.

The state of the atmosphere, as we have just seen, greatly influences the amount of dew. When the air is clear the dew is abundant; when cloudy, little or no dew is formed. In this case the clouds radiate heat to the earth, and this prevents the earth from cooling so rapidly. A strong wind prevents the formation of dew by removing the strata of air next the earth before they have time to be cooled down to the point of saturation, or the dew-point. A gentle breeze may, in some cases, facilitate the formation of dew by replacing the layer of air from which the moisture has been deposited by another which contains more moisture. WHITE FROST is frozen dew. As all bodies have not the same capacity for radiating heat, and as some cool more rapidly than others, it follows that with the same exposure on a summer night some bodies will be densely covered with dew, while others remain perfectly dry.

Under the head "Expansion" experiments have been mentioned which illustrate the expansion of gases on the application of heat. The ordinary fire-balloon is a further illustration of this. The common fire-balloon is constructed of some light material, generally tissue paper; a piece of tow, soaked in spirits of wine, is attached to the underneath opening. When this is

set on fire a current of warm air rises, and the balloon is soon filled with such air. It is lighter than the surrounding air, and therefore will ascend, as a cork would if placed at the bottom of a vessel of water.

In a room, when a fire is kindled, a current of air is caused by the heat, in a manner similar to this. The air near the fire becomes hot, therefore light, and ascends; neighbouring bodies of air rush in to supply the place, and a constant current is produced. A fire not only warms a room, but also ventilates it. Every substance at a higher temperature than the air in a room, as our bodies, gas flames, &c., is engaged in imparting its heat to the surrounding air, and this, loaded with impurities, ascends. To ventilate thoroughly a room, therefore, provision should be made for egress near the ceiling, and for ingress of fresh air near the floor, so that a constant current may be flowing. The sun, in equatorial regions, is a powerful heat-giver to the atmosphere, and is thus the cause of currents which we call winds.

Winds.—Wind is air put in motion. The air is never entirely free from motion, but its direction and velocity are continually changing. The principal cause of these movements of the atmosphere is the variation of temperature produced by the alternation of day and night, and the succession of the seasons. When, through the heat of the sun, a portion of the earth's surface is heated to a greater degree than the remainder, the air resting upon it becomes rarefied and ascends, while a current of colder air rushes in to supply the vacancy. Thus two distinct currents will be produced—the one warm moving out, and the other cold, moving in. To these movements of the atmosphere we apply the term wind.

The direction of the wind is subject to constant

interruption from mountains, deserts, plains, oceans, and seas. Mountains covered with snow condense the air brought into contact with them, and when the temperature of a current of air is changed, its direction is likely to be changed. The ocean is never heated to the same degree as the land. The consequence is, that the general direction of the wind is from tracts of ocean to tracts of land. In those parts of the globe which present an extended surface of water the wind blows with great regularity.

Winds are divided into three classes—regular winds, periodic winds, and variable winds.

Regular winds are those which blow throughout the year in the same direction. They occur in the neighbourhood of the equator, and extend about 30 degrees on each side. From their advantage to commerce they are called trade winds. On the north side of the equator they blow from the north-east, and on the south side they blow from the south-east. These winds arise from currents of air flowing from the polar regions towards the equator. The velocity of the earth about its axis being greater as we approach the equator, these winds lag behind, as it were, and become inclined, so as to blow towards the west, giving north-east winds on the north side, and south-east winds on the south side.

Periodic winds are those which, at regular intervals of time, blow from opposite directions. Such are monsoons, that prevail in the Indian Ocean, blowing one half the year from north-east to south-west, and the other half in the opposite direction. When the sun is on the north of the equator, the southern portion of the Asiatic continent, and the northern part of Africa, consisting of the Sahara region, are warmer; consequently for one half the year the direc-

tion of the trade wind is changed, and it blows from south-west to north-east.

Variable winds are those which blow sometimes in one direction, sometimes in another. The further we remove from the equatorial regions the more variable are the winds.

Clouds are masses of watery vapour evaporated from the earth, and partially condensed in the higher regions of the atmosphere. When air saturated with vapour, near the surface of the earth, is cooled down rapidly, its vapour is condensed.

If the condensation is not sufficient to allow it to fall in the form of drops of rain, it floats above the surface of the earth as mist or fog. Clouds differ only in one respect from a fog: they float in the atmosphere at a greater elevation. We must not overlook the effects of expansion as causes of clouds and rain. As the air ascends it is relieved from pressure, and consequently expands. At a height of 16,000 feet it occupies twice its volume at the sea level. The same amount of vapour particles containing heat are spread through twice the space, giving up their heat, which is materially expended in removing other bodies of air from the space which the expanded body assumes. This vapour cannot be held in an invisible state after the temperature is thus so materially lowered. No doubt this is the cause of the cloudy sky and constant heavy rain of equatorial regions.

Rain is a fall of drops of water from the atmosphere. When several vesicles of vapour, through condensation in the clouds, unite, the weight becomes too great to be supported by the air, and the drop thus formed falls to the ground. Rain falls most abundantly in *countries* near the equator, and decreases *as we approach* the poles. The quantity of rain that

falls in any country depends upon its neighbourhood to the ocean or large bodies of water, upon the season, upon the temperature, and the prevailing direction of the winds. More rain falls near the coast than in the interior of the country; more rain falls in summer than in winter; more rain falls in tropical than in temperate climates; and more rain falls in those countries where the prevailing winds are from the ocean. The average yearly fall of rain in the tropics is ninety-five inches; in the temperate zone it is only thirty-five. The depth of rain which falls yearly in London is about twenty-five inches, but at Vera Cruz, in the Gulf of Mexico, it is two hundred and seventy-eight inches. The explanation of this is to be found in the peculiar situation of the city, at the base of lofty mountains whose summits are covered with perpetual snow. Against these mountains the hot, humid air from the sea is driven by the winds, it is condensed, and its excess of moisture is precipitated as rain on the city of Vera Cruz. The mountain chains of the west coasts of England and Ireland receive, with the west and south-west winds which generally prevail, the vapour of the Gulf Stream; in consequence, the annual fall of rain is much greater on the south-west side of the mountain chain than it is on the eastern and southern coasts, or the north-east side of that range of mountains which stretch along the coasts of England and Ireland.

The total amount of rain which fell at various stations in Ireland in 1851 is given in inches as follows:—

Portarlington	21·2
Killough	23·2
Dublin	26·4
Castletownsend	42·5
Westport	45·9
Cahirciveen	59·4

Thus Portarlington lies to the north-east of Slievebloom, Killough to the north-east of the Mourne range, Dublin north-east of the Wicklow range. On the other hand, the stations of greatest rain—Cahirciveen, Castletownsend, and Westport—are near to high mountain ranges, but on a different side.

The atmosphere.—The per-centage composition of the air is as follows :—

		Chem. Symbol.
Nitrogen . .	79·5 . .	N
Oxygen . .	20·0 . .	O
Water vapour .	·45 . .	H_2O
Carbonic acid gas .	·05 . .	CO_2

and traces of ammonia, &c.

Nitrogen gas is remarkable for its negative properties, and the purpose it serves in the atmosphere appears to be chiefly that of modifying the violent action of the oxygen.

Oxygen gas is the life-supporter, both animal and vegetable. It is by the inhalation of the oxygen of the air, and its eventual combination with the carbon of our food, that the functions of life are performed. The result of the combination is CO_2.

Carbonic acid gas is the deadly poison produced by decaying animal and vegetable matter combining with oxygen from the air. It is thrown off alike by ourselves in breathing, and by a gas flame or a fire burning—especially a coke fire, which is nearly pure carbon. When there is a deficient supply of air, the carbon combines with a smaller quantity of oxygen, producing carbonic oxide (CO), a still more deadly poison. Hence the evil of burning coke or charcoal in a close room without chimney.

Water Vapour.—This in a vaporous state is the vehicle by which immense quantities of heat are gradually

imparted to the earth. The specific heat of water is very high, and in addition there is the latent heat of vapour which is given up when water assumes a liquid state. The terms specific and latent heat will be understood from what is said in the next paragraph. There is also, especially near large towns, a quantity of sulphurous acid gas (SO_2), a compound of one atom of sulphur with two of oxygen, which is highly injurious to animals and plants. It will be remembered that CO_2 and SO_2 were referred to under another head as exceptional with regard to other gases.

Specific Heat.—Different substances require different degrees of heat to raise them to the same temperature. This is called specific heat. The specific heat of a body may be defined to be the quantity of heat necessary to raise it to a given temperature compared with the quantity required by water under the same circumstances. Water is taken as the standard: for example, if water be taken as 1, then mercury will be ·033.

If 1 lb. of water at 100° be mixed with 1 lb. at 40° the mean temperature will be $\frac{100^\circ + 40^\circ}{2} = 70^\circ$.

In the same way, the mean temperature of the same liquids may be found when mixed together:—oil $\frac{80+20}{2} = 50^\circ$; mercury $\frac{140+40}{2} = 90^\circ$.

But if 1 lb. of water at 100° be mixed with 1 lb. of olive oil at 40°, we shall not have the mean temperature of 70°, but 80°. In the same way, if 1 lb. of mercury at 40° be mixed with 1 lb. of water at 100°, we shall have a temperature of 98°. Now the water parted with 20° of heat in the case of oil, which was sufficient to raise the temperature of the oil 40°, that is, from 40° to 80°.

In the case of the mercury, the water parted with only 2°, which was sufficient to raise the mercury 58°, from 40° to 98°: equal weights of the liquids being taken in the experiment. From these experiments it appears that equal weights of water, oil, and mercury require different degrees of heat to raise them to the same temperature. It is instructive to note the immense influence which water and water vapour exercises upon the earth by its high specific heat. In winter the ocean is constantly giving up its stores of heat to the winds that blow over its surface, and by them it is carried to the land, rendering it habitable. Again, take the case of the Gulf Stream, whose waters on arriving at the shores of Western Europe are said to be 5° hotter than the surrounding ocean:—

Specific heat of water is 1.
" " air " ·24.

So that 1 lb. of water will heat 4 lbs. of air to its own temperature. But water is 770 times heavier than air. Then, comparing equal *volumes*, 1 cubic foot of water giving up one degree of heat would raise $770 \times 4 = 3{,}080$ cubic feet of air one degree.

Solids may be easily experimented on. If 1 lb. of iron be taken and raised to a given temperature, and immersed in 1 lb. of water at a known temperature, we can easily determine the specific heat by the increase of temperature, the same as by mixing two liquids at a different temperature. Specific heat is generally taken with reference to equal weights rather than equal volumes. 1 lb. of water, in rising to a given temperature, requires or absorbs thirty times more heat than 1 lb. of mercury. If mercury be taken as 1, water will be 30. The great specific heat of water is very important: it rises in temperature slowly, and parts with its heat slowly, which tends to equalize

the temperature of the air and earth. The small specific heat of mercury is useful. No relation exists in the table of specific heats when *equal weights* of different bodies are taken; but if *atomic* weights be taken, then we have a relation. Let us take 16 oz. of sulphur, 28 of iron, and 32 of phosphorus. Let these equivalent quantities be then raised to the temperature of 212°, and afterwards immersed in water at 60°, so as to observe how much each raises the temperature of the liquid. By such an experiment we shall find that 16 parts of sulphur and 28 of iron will raise the water to the same temperature, while the phosphorus will raise it four times higher. It thus appears that the specific heats of sulphur and iron, when taken in equivalent quantities, are the same, whilst phosphorus is four times greater. The specific heats appear to have a close connection with the atomic weights. A high specific heat is found with a metal that has a low atomic weight, and *vice versa*.

If metal balls of iron, lead, bismuth, tin, and copper, be taken and raised to the same temperature, by immersing them in oil at 180° C., and after a few minutes we place them on a cake of beeswax, about 6 inches in diameter and half an inch thick, which is supported on the large ring of a retort stand, we shall find that the iron and copper melt their way through, and that the tin, lead, and bismuth have penetrated but a small distance. If we take as unity the amount of heat given out by a pound of water in falling through one degree of temperature, the following table of Professor Tyndall's will express the amount of heat given out by a pound weight of each of the following substances:—

Water	1·0000
Sulphur	0·2026

Arsenic	0·0814
Antimony	0·0508
Bismuth	0·0308
Zinc	0·0955
Cadmium	0·0567
Tin	0·0562
Lead	0·0314
Iron	0·1138
Cobalt	0·1070
Nickel	0·1086
Copper	0·0951
Silver	0·0570
Gold	0·0324
Platinum	0·0324
Mercury	0·033
Alcohol	0·067

The calorimeter of Lavoisier and Laplace (*Fig.* 85) is used for ascertaining the specific heats of solids and liquids. It consists of inner and outer cells, independent of each other, and with separate outlets at the base. The outer vessel, A, is filled with lumps of ice, which are constantly renewed as they waste, the waste water falling into *m*. The inner vessel B is also filled with ice. In the centre of this is placed the substance to be experimented upon. It will be reduced to a freezing temperature, and the heat it gives up will be expended in melting ice contained in B; the water is received in *n*, and its quantity carefully compared with the quantities obtained in other experiments. Calculations dependent on specific heat will be found in *Exercise VI.*

Latent Heat.—When any solid body is converted into a liquid, a large amount of heat is observed to enter it without raising its temperature. This heat serves to liquefy the body without increasing its tem-

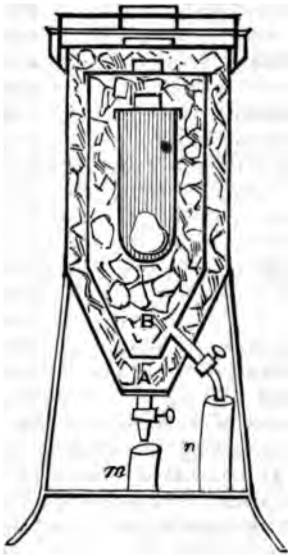


Fig. 85.

perature. The water which flows from melting ice is no hotter than the ice; the heat it contains is not sensible, nor does it affect the thermometer; it is called latent heat. If a piece of ice be hung in a warm room it melts slowly. This would not be the case if only a small amount of heat was necessary to liquefy it. It gathers heat from surrounding objects, which is all expended in liquefying the body. If a cubic inch of ice be taken and a cubic inch of water, and the temperature of the water lowered to 32°, and the ice and water removed into a warm room, and a thermometer placed in the water, we shall be able to

ascertain the amount of heat the water receives in a given time. Let us suppose the thermometer to rise 7° every half-hour, and that the time be observed till the whole of the ice is melted. There will be 14° of heat added every hour: by these means we shall be able to ascertain how much heat disappears, or becomes latent, in converting the ice into water. It will take $10\frac{1}{2}$ hours to liquefy the ice. The water in this experiment was only 32°. Now, if we multiply $14 \times 10\frac{1}{2} = 147$, the number of degrees of heat absorbed or rendered latent in converting the ice into water; in other words, 147° of heat have become latent.* If we take 1 oz. of powdered ice or snow, and 1 oz. of water at 175°, the ice will be melted, and we shall have 2 oz. at 32°. The water lost 143° of heat, and the ice absorbed it; but if we take water at 32°, and water at 172°, we shall have the mean temperature of 102°. What we have said as regards ice, holds good with all solids: a certain amount of heat is in all cases rendered latent. The following table shows the latent heat of different bodies:—

	F.	C.
Water	143°	79·4°
Sulphur	145°	80·5°
Lead	162°	90·0°
Wax	175°	97·2°
Tin	500°	277·7°

When water freezes, the 143° of heat abandons it and manifests itself in a free or sensible state. If a flask of boiling water be saturated with sulphate of soda, the cork withdrawn and a rough body introduced, the soda will become solid, and the sudden

* 143° is correct; so that 147° must be regarded as an approximate number only.

conversion of the liquid into a solid causes it to part with its heat; if a thermometer be introduced the mercury in it will rise 30° or 40°: this is precisely what takes place in the freezing of water. Solids in becoming liquids render a large amount of heat latent, and liquids in becoming solids part with the heat previously rendered latent.

When solids are compelled to liquefy rapidly without a free supply of heat, the temperature of surrounding objects is lowered. Salt in water, or nitre, causes the thermometer to fall several degrees. If sulphate of soda and snow be mingled together the temperature falls to zero. Chloride of calcium mixed with snow, lowers the temperature so as to freeze mercury. These are called freezing mixtures.

Latent Heat of Gases.—It is not necessary for a liquid to boil in order to produce vaporization. The drying up of water by its gradual conversion into vapour is a phenomenon with which we are all familiar.

If water be raised to 212° it is converted into steam, but the steam is of the same temperature as the water. If it were only necessary to raise water to 212° to convert it into vapour, it would, as soon as it attained that temperature, explode into steam, like gunpowder. A cubic inch of water will make a cubic foot of steam. If vapours contained no more heat than the liquids, they would immediately condense into liquids as soon as they came into contact with any body lower in temperature; but it is found necessary to expose them to a great amount of cold. Ice in becoming water renders a large amount of heat latent; water in becoming steam also renders a large amount of heat latent: what occurs with water occurs with all liquids. If a vessel filled with water at 32° be placed over a

regular source of heat, and the time observed necessary to raise it to 212° be one hour, it will require five times longer before the water is entirely converted into steam. Now the water has been raised through a temperature of 180°, say in one hour; we multiply 180×5, which is the number of hours taken, and we get 900°: yet the steam has only the temperature of 212°. What has become of this enormous amount of heat? It has been rendered latent in the steam, and this can be demonstrated by condensing the steam, and observing the amount of heat evolved. Let the steam be conducted into ice-cold water, and it will part with its latent heat, and raise the water to its boiling point. If 11 cubic inches of water be taken at 32°, and raised to 212° by the steam of 2 cubic inches of water, we shall have 13 cubic inches at 212°; 2 cubic inches of water in the form of steam have raised 11 cubic inches of water 180°, and the whole 13 cubic inches have a temperature of 212°. If a cubic foot of steam at 212° be contained in a close vessel, and 5½ inches of ice-cold water, at 32°, be injected into this vessel, we shall have 6½ cubic inches of water at 212°. Now it is evident that in returning to a state of water the steam has given out sufficient heat to raise 5½ cubic inches of water from 32° to 212°. The heat which was latent in the steam has now been made sensible in raising the 5½ cubic inches of water through 5½ times 180° of heat, viz., 990°. Now let us take a connected view of latent heat with regard to ice, water, and steam; let us trace the history of a block of ice until it assumes the form of vapour. Commence with a block of ice at 0° C., weighing 1 lb. Heat is applied, the ice liquefies; in so doing, it absorbs 79·4° C. or 143° F. of heat; this is the latent heat of water. In rising from 0° to 4° C. the

water contracts. From 4° C. to 100° C. it expands. At 100° C. it begins to assume the form of steam or vapour. The water rises no higher in temperature, yet heat is supplied for some time. It is absorbed by the water changing its state of aggregation. Steam requires 537·2° C. or 967° F. as its latent heat. Calculations on latent heat will be found in *Exercise VII.*

It has been already stated that all liquids, like water, when entering the vaporous state absorb immense quantities of heat. Place a drop of water and a drop of ether on the skin; the latter will evaporate rapidly, giving a sensation of cold far stronger than any perceived from the evaporation of the drop of water. That cold is produced by evaporation is clearly illustrated by a simple apparatus called the cryophorus, or ice-carrier (*Fig.* 86). This simple piece of apparatus

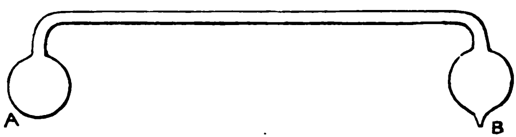


Fig. 86.

is made of glass; before the bulb B is hermetically closed, the water in A is boiled, and B is closed at the instant the bulbs and pipe are full of the vapour of steam. We may then look upon the interior as a partial vacuum; and, indeed, this may be shown by allowing the water to fall from one end of the instrument to the other, when it will be noticed that the water falls as in a vacuum, giving a sharp sound as if the contents were metallic, because there is no cushion of air to relieve the fall. To use this instrument, place bulb A in a tumbler glass to prevent draughts of air from retarding the desired effect. Let bulb B be placed in a

second tumbler. Around this bulb, in the second tumbler glass, put a freezing mixture, as ice and salt, finely pounded; the vapour in B will be condensed, more vapour will come off from A. At this stage two points must be kept in view. 1st, the vapour is readily produced from A, because there is little or no pressure on the surface of the water. 2nd, the vapour cannot be produced without absorbing a large quantity of heat that becomes latent. This last vapour is again condensed in A, until the heat is so far removed from this bulb that a coating of ice, half an inch thick, may with ease be obtained.

Combustion.—Candle and Gas Flames.—The Diamond.—Animal Heat.—An Ordinary Fire. —When we clearly understand what takes place in the burning of a common candle, all other examples of combustion are readily understood. Let *Fig.* 87 represent a candle flame. The flame is supported by the burning of the melted or vaporous tallow, which flows up the wick by capillary attraction. Tallow is chiefly hydrogen and carbon. In part 1 of the flame there is no combustion going on. Place a piece of glass or wire gauze on the top of the flame, press it down to the middle, and look into this part of the flame; it will be found to be hollow. Again, take a piece of glass tubing of small bore, put one end of it in this part of the flame, bend it twice at right angles, and pass the other end nearly to the bottom of a vessel of cold water; it will be found that solid tallow will collect at the bottom of this vessel. Now there is chemical affinity or attractive force at work between the atoms

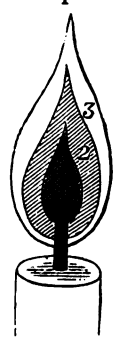


Fig. 87.

of hydrogen and carbon of the flame and the oxygen of the atmosphere; but this affinity is much stronger between H and O than between C and O. Imagine a kind of struggle here, whereby the H and C separate, the H hastes to effect combination with the O, leaving the C behind. This combination between H and O takes places with such energy that an enormous amount of heat is developed. Next comes the combination of the C with O; but in order to effect this, the laggard C has to traverse part 2 of the flame, where its solid particles are raised to a white heat, and this it is which gives the light. There can be no light without solid matter raised to a high temperature. That part 2 consists of H and O the glass plate before employed will show, by the moisture deposited upon it, which is, of course, H_2O, or water. Part 3, the blue shell outside the candle flame, is the portion of the flame due to the combustion of C; that is, its combination with O. With a piece of glass tubing the CO_2 (carbonic acid gas) may be collected and passed into lime water, where it will produce the solid white precipitate, carbonate of lime.

The combustion in ordinary flames is never complete; much of the carbon passes off in the form of soot. This will be demonstrated by holding a sheet of paper, or, better, a plate of glass over the flame. A better supply of O will make the combination more complete, and then the carbon cannot be so obtained. With a blowpipe supply more air to the candle flame; there will only be a slight deposit of soot, and there will be a great increase to the intensity of the flame. The C can effect combination with the O without traversing the heated cone, 2; and, by its combination, adds to the heat generated; whilst the heat from the

action between H and O is not expended upon the C, therefore it is also at liberty. We place a light to the candle to raise the elements to a sufficiently high temperature to effect combination; this is afterwards kept up by the flame itself, so long as the substances last.

A gas flame may be looked upon as an enlarged candle flame. The materials of combustion are chiefly H and C, as before; and the three parts of the flame may be proved to exist as before, and to throw off the same compounds. How necessary, then, it must be in a small room, or in a large room when many lights are used, to provide for the escape of this deleterious gas, CO_2.

A modification of the gas flame may be obtained with a Bunsen's burner, which is a very simple contrivance for supplying the flame with a large quantity of air.* *Fig.* 88 will assist the student in comprehending its principle. Gas enters by pipe *m*, holes at the base of pipe *n* admit the air, and the combustion takes place at the top of *n*; the flame gives out intense heat, and little or no light. By stopping the holes at the base of *n*, it will be at once seen that an ordinary gas flame is produced, and that incomplete combustion is giving off, again, carbon in large quantities.

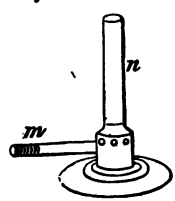


Fig. 88.

In a coal or coke fire, at the bottom of the fire C combines with O, producing CO_2; in the middle of the fire $CO_2 + C$ gives CO, or carbonic oxide, because here there is a scanty supply of O; towards the top of

* The air supplied mixes with the gas intimately, and when combustion commences, all the H and C can at once enter into combination with O, giving intense heat but no light.

the fire, there is more O again, and CO+O gives CO_2, which burns with a blue lambent flame.

This combustion is constantly going on in our own bodies; the carbon which we take as food combines with the oxygen of the air we breathe, and we throw off CO_2. This may be proved by breathing into a tube which contains lime water, when insoluble carbonate of lime will be produced, giving a milky appearance to the water.

The diamond, Newton declared long ago, was composed of some combustible matter. We know that it is pure carbon, or graphite, and that when burnt in oxygen the production is simply CO_2, nothing else. Here, by the help of the mechanical theory, we can form perhaps a clear idea of what is actually taking place when the diamond is burning in O; there is chemical affinity or attractive force between the C and O. The little atoms of O from all sides rush to the C, their motion is stopped, and it is translated into heat; hence the intense white heat seen, and the star-like appearance produced by the combustion of the diamond.

Diathermancy.—This term is applied to a property possessed by some substances of transmitting the heat rays which strike upon their surface. It is analogous to the term "transparency" as employed when speaking of glass. A substance which will not permit the heat rays to pass through may be termed "athermanous."

For experiment use plates of glass and rock salt. Place the glass between your face and a hot fire; the light will pass through the glass, but the heat will not. Glass is a suitable material of which to make fire-screens. Now put the plate of rock salt between your face and the fire, and a remarkable difference will be noticed, the heat rays will pass through and strike your face as

if there were no substance between it and the fire. Rock salt possesses this property of diathermancy in a high degree.

The following table of Professor Tyndall's will further illustrate the subject:—

Substance.	Per-centage of heat transmitted.
Rock-salt	92
Iceland spar	39
Amber (artificial)	21
Amber (natural)	11
Ice	6

Reflection and Refraction of Heat.—A ray of heat radiated from the surface of a body proceeds in straight lines until it meets some reflecting surface, when it is thrown off, according to the law that the angle of incidence is equal to the angle of reflection. A concave mirror is a reflecting surface curved towards the source of heat. For experimental purposes they are generally parabolic in shape. It is a property of such mirrors that all rays which before incidence are parallel to the axis, after reflection converge to a single point, which point is the focus of the mirror:

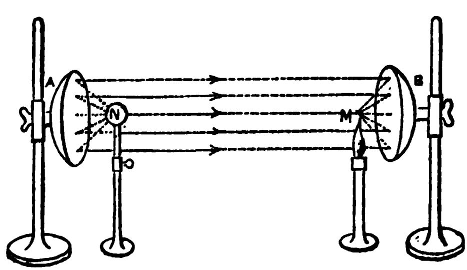


Fig. 89.

and conversely, if the rays radiate from the focus, they will be reflected in lines parallel to the axis.

Let *Fig.* 89 represent two parabolic reflectors, having their axes coincident, and their surfaces turned to each other. In the focus N of the mirror is placed a red-hot iron ball, and in the focus M of the mirror is placed a piece of phosphorus. The heat radiating from the ball is reflected from the reflector A, falls on the surface of the reflector B, is again reflected to the focus M, and the heat concentrated is sufficient to inflame the phosphorus, even when the reflectors are several yards distant from each other. If only the reflector A were used the phosphorus could not be ignited. With a parabolic reflector the rays of the sun can be so concentrated as to ignite inflammable substances. A differential thermometer may, for some experiments, be placed in the focus M instead of phosphorus. That heat is refracted according to the laws of light may also easily be shown. Make a lens-shaped bag of some thin material, fill it with a dense gas, as CO_2, then use it as a lens; the focus of the heat rays may be found by means of phosphorus or by a thermometer. A lens of rock-salt, or any other diathermanous substance, will have the same effect.

Reflecting Power of Different Bodies.—Those bodies which reflect a large portion of the incident heat are called good reflectors; those which reflect but little incident heat are called bad reflectors. Leslie's apparatus for determining the relative reflecting powers of different bodies consists of a cubical tin box filled with water at the boiling point, and placed in front of a parabolic reflector. The rays of heat falling on the reflector A are thrown back, and tend to come to a focus at N; but by interposing a square plate of some substance between the reflector A and

its focus, the rays are again reflected and come to a focus between the plate and the front of the reflector. The heat so reflected is received on a differential thermometer, by which it is measured. By interposing plates of different substances in succession their relative reflecting powers are determined. In this experiment only one reflector is used.

The Dynamical Theory of Heat (taken chiefly from Professor Tyndall's *Heat considered as a Mode of Motion*).—That motion and heat were so intimately connected as to be equivalent, varying in form, but the same in nature, and easily transferable from one form to the other, without waste or destruction of even the smallest portion of the force, has long been accepted by scientific men. To demonstrate this by exact experiment beyond a shadow of doubt, has, however, taken up much time, and required the greatest care and abilities on the part of the experimenter.

As ordinary examples for illustration that heat is a form of motion, or rather that which motion develops when it is suddenly checked or gradually diminished by friction, we can call to mind the Indian taking up two pieces of dry wood, rubbing them together, and obtaining fire. Again, when the brake is put on a railway carriage, the friction of the wheel on the rail throws off fire in the form of clouds of sparks. Other examples in ordinary life will occur to the thoughtful student. By the use of a multiplying wheel, and a piece of wood or metal attached to the axis of the smaller wheel, we shall have a clear demonstration that heat is obtained by motion. Place two pieces of wood, so as to touch the revolving piece, or enclose it in a piece of copper, when either wood or copper will give unmistakable signs of being subjected to the action of heat. Our own bodies may be said to be

constantly renewed by the application of heat, which is expended in motion; and it is well known that an extra amount of motion or expenditure of heat results in an extra call for supply of heat-giving materials to the body. The envelope which surrounds the sun, and is known to astronomers as the zodiacal light, may be a crowd of meteors moving with immense velocity towards the sun, and from this source the annual loss is made good. In the same way combustion may be due to the clashing together of the particles of oxygen and the constituents of the lighted body. All cases of combustion are ascribed to this collision of particles urged together by the force of chemical attraction. A leaden bullet is placed on an anvil, and struck with a sledge-hammer. The amount of heat generated by percussion is sufficient to raise the temperature of the bullet; and if the heat generated could be collected without loss, "we should be able, by means of it, to raise the hammer to the height from which it fell." An elevation of temperature is also produced by compression and friction, and the mechanical force expended in producing heat may be expressed in equivalents of heat and work.

To Dr. Joule, of Manchester, belongs the honour of giving experimental proof of the equivalency existing between heat and motion. He placed water in a vessel, agitating it by paddles, then mercury was used instead of water, and afterwards oil. He caused discs of cast iron to rub together. He urged water through capillary tubes, and in every case ascertained the quantity of heat produced, and the amount of mechanical force employed to produce that heat; "the absolute amount of heat generated by the same expenditure of power was in all cases the same."

In this way it was shown that the heat necessary to

raise 1 lb. of water 1° F. is equal to that generated by a pound weight falling to the earth from a height of 772 feet. Conversely, this amount of heat would raise a pound 772 feet high, or 772 lbs. 1 foot in height. The term "*foot pound*" is employed as a unit to represent in a convenient way the lifting of one pound one foot high. *The mechanical equivalent of heat* is then 772 foot pounds. For 1° centigrade, 1,390 foot pounds is the equivalent. The heat generated increases as the height.

EXAMPLE.—A 64-lb. cannon ball at a temperature of 30° C. falls from a height of 4,170 feet. Supposing that all the heat generated is communicated to the ball, what will be its temperature at the instant of striking a metallic plate on the ground?

1 lb. of water falling 1,390 feet generates 1° C.

1 lb. of iron falling 1,390 feet generates 9° C. (sp. heat of iron).

1 lb. of iron falling (1,390 × 3) 4,170 feet generates $9 \times 3° = 27°$ C.

Each pound of iron would be raised 27° C.; this added to $30° = 57°$ C., the temperature of the cannon ball. (*Exercise VIII.*)

We have stated that stoppage of motion generates heat; this applies to projectiles travelling horizontally as well as to bodies falling vertically.

To understand this, and to make calculations from it (*Exercise VIII.*), carefully study and remember the following points:—

1st. *A vertical distance of 772 feet equals a velocity of 223 feet per second.*

2nd. *Height is proportional to the square of the velocity.*

3rd. *Heat generated increases as the height.*

4th. *Therefore heat generated increases as the square*

of the velocity, i. e., *double the velocity and we shall have four times the heat.*

EXAMPLE.—A leaden bullet at a temperature of 10° F. strikes a target at a velocity of 669 feet per second. What is the temperature of the bullet at the moment of striking, supposing all the heat generated to be in the bullet?

$$\frac{669}{223} = 3. \quad 3^2 = 9.$$

Specific heat of lead is 1-30th that of water.

Therefore $1 \times 30 \times 9 = 270$.

The bullet will be at 270° F.

Material Theory of Heat.—This supposes that heat is a material substance which is projected in every direction by a heat-emitting body with immense force and at an extreme velocity. It is a theory not much in favour at the present day, for reasons which will occur to the student who tries to account for the phenomena of heat by means of this theory. As an example, let us take specific and latent heats.

The specific heats of the metals, &c., are said to be caused by the material particles of heat getting in between the molecules of the metal, and that the spaces between the molecules are larger in those which are of a high specific heat, and therefore require a larger amount of the material heat to fill them; hence their slow rise in thermometrical heat compared with the more compact substances of lower specific heat.

The theory will apply to latent heat with great readiness; for when a solid passes into a liquid state we know that its particles lay in a much looser contact than before.

Then the heat is said to be required in large quantities to fill the interstices, and this applies still more

to the vaporous state, where the substance is enormously expanded.

Specific Heat at Constant Volume and at Constant Pressure (taken chiefly from Tyndall's *Heat a Mode of Motion*).

In *Fig.* 90, for a reason which will shortly appear, let us suppose the piston to weigh 33 oz., and from B to P to measure 273 inches. This part of the cylinder is filled with air at 0° C. Let the area of the piston be 1 square inch. Every addition of 1° of heat raises the piston 1 inch; that is, for every degree centigrade the volume increases 1-273rd of the original volume. So that by heating the air 273° C. its volume would be doubled.

Piston weighs 33 oz.; pressure of the air is 15 lbs., or 240 oz. $240 + 33 = 273$ oz. The pressure is constant.

Then air does work; it lifts 273 oz. a height of 273 inches.

Again, instead of at constant pressure, let us keep the air at constant volume. The air must not be allowed to expand. For every degree of heat added put on the piston 1 oz. of weight; 273 oz. for 273° C. Here, then, to keep the volume constant, we must double the original pressure. Compare the two experiments.

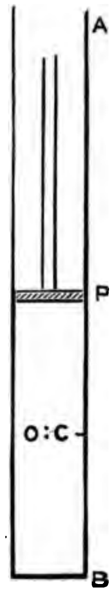


Fig. 90.

In the first experiment we raised the heat from 0° C. to 273° C., doubling the volume, whilst the pressure was the same, raising 273 oz. 273 feet high. In the second experiment we raised the temperature from 0° C. to 273° C., but do not permit the air to *lift any weight*. We add to the pressure to keep the volume constant.

The quantity of matter treated is the same. The final temperature is the same. The absolute quantities of heat differ. If 10 grs. of combustible matter would give the heat for the second experiment, it would take $14\frac{1}{4}$ grs. for the first. The heat given out by the additional $4\frac{1}{4}$ grs. is expended in *lifting the weight*. More correctly, the proportions are as 1 : 1·421.

From this the mechanical equivalent of heat may be deduced :—

Let C contain 1 cubic foot of air at 0° C., P P represent 1 square foot of surface, and A P be 1 foot in height. Raise the heat so as to double the volume. Now in doing this the air is lifted up, or pushed back to P′ P′.

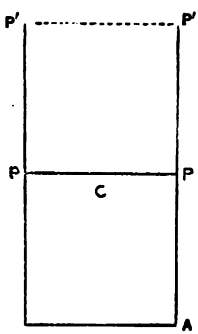


Fig. 91.

$$144 \times 15 = 2{,}160.$$

2,160 lbs. are raised 1 foot high. 1 c. ft. of air weighs 1·29 oz. Sp. heat of air is ·24 ; of water, 1.

Then the heat which would raise 1 c. ft. of air to 273° C. would raise only ·31 oz. of water up to 273° C. (Here we will change 273° C. to its equivalent, 490° F., for convenience in calculation, and in order to bring out the ordinary mode of expressing the equivalent of heat.) But ·31 oz. of water heated to 490° F. is equal to 152 oz. or $9\frac{1}{2}$ lbs. heated 1° ; so that the heat which raised 2,160 lbs. 1 foot high will raise $9\frac{1}{2}$ lbs. of water 1°.

The air was heated under constant pressure, which varies in the amount of heat necessary when the volume is constant, as— 1·42 : 1,

Then, as 1·42 : 1 : : 9·5 lbs. : 6·7 lbs.

$$9{\cdot}5 - 6{\cdot}7 = 2{\cdot}8 \text{ lbs.}$$

So that the *excess of heat* imparted to the air when it was allowed to expand can raise 2·8 lbs. of water 1°, and we saw that this could raise 2,160 lbs. 1 foot in height. Therefore—

$$\frac{2160}{2 \cdot 8} = 771 \cdot 4, \text{ the mechanical equivalent of heat.}$$

Extracts from the Second Book of the "Novum Organum."—"When I say of motion that it is the genius of which heat is a species, I would be understood to mean not that heat generates motion, or that motion generates heat (though both are true in certain cases), but that heat itself, its essence and quiddity, is motion and nothing else, limited, however, by the specific differences which I will presently subjoin, as soon as I have added a few cautions for the sake of avoiding ambiguity.

"Nor, again, must the communication of heat, or its transitive nature, by means of which a body becomes hot when a hot body is applied to it, be confounded with the form of heat; for heat is one thing and heating another. Heat is produced by the motion of attrition without any preceding heat.

"Heat is an expansive motion, whereby a body strives to dilate and stretch itself to a larger sphere or dimension than it had previously occupied. This difference is most observable in flame, where the smoke or thick vapour manifestly dilates and expands into flame.

"It is shown also in all boiling liquid, which manifestly swells, rises, and bubbles, and carries on the process of self-expansion till it turns into a body far more extended and dilated than the liquid itself, namely, into vapour, smoke, and air.

"The third specific difference is this:—Heat is a

motion of expansion, not uniformly of the whole body together, but in the smaller parts of it; and at the same time checked, repelled, and beaten back, so that the body acquires a motion alternate, perpetually quivering, striving, and struggling, and irritated by repercussion, whence springs the fury of fire and heat.

"When wind escapes from confinement, although it bursts forth with the greatest violence, there is no very great heat perceptible, because the motion is of the whole, without a motion alternating in the particles.

"In cold, contractive motion is checked by a resisting tendency to expand, just as in heat the expansive action is checked by a resisting tendency to contract. From this it follows that the form or true definition of heat (that is, heat in relation to the universe, not simply in relation to man) is, in a few words, as follows:—*Heat is a motion expansive, restrained, and acting in its strife upon the smaller particles of bodies.*"

HEAT.

List of Necessary Apparatus.

	£	s.	d.
Metal bar and gauge for expansions	0	4	0
Compound bar for unequal expansion	0	2	0
Thermometer tubes	0	2	0
Apparatus to show force of contraction	0	7	0
Differential thermometer	0	15	0
Mercurial thermometers—			
Graduated on stem	0	4	0
,, on wood	0	1	0
Alcohol thermometers	0	1	0
Glass tube, narrow bore, large bulb	0	1	6
Cryophorus	0	2	6

	£	s.	d.
Pair of concave tin reflectors, on stands .	0	10	0
Iron ball and stand	0	3	0
Two Leslie's canisters	0	4	0
Wire gauze	0	1	0
Faraday's convection apparatus . .	0	3	0
One tin reflector blackened for reflection and absorption, with above reflectors and stands	0	2	0
Useful wooden clamp	0	5	0
Bunsen's burner	0	1	6

Additional List of Apparatus.

	£	s.	d.
Ferguson's pyrometer for expansion of metals	1	11	6
Six barometer tubes, to show the elastic force of different vapours	0	5	0
Whalebone rod, to remove air bubbles from barometer tubes	0	1	0
Earthenware dish for pouring mercury .	0	0	6
Pneumatic syringe	0	3	0
Pair of reflectors, copper silvered . .	1	10	0
Tin-plate vessel, with tubulures for conduction, including metal bars . . .	0	10	0
Wood cylinder, with broad brass ring for conduction	0	2	0
Davy lamp	0	6	0
Daniell's hygrometer	2	2	0
Marcet's steam apparatus	3	10	0
Mercury trough	0	6	0
Thermo-multiplier, 48 pairs	2	10	0
Multiplying wheel, for developing heat by friction	1	10	0
Carre's freezing apparatus . . .	6	0	0

PROBLEMS IN ACOUSTICS, LIGHT, AND HEAT.

EXERCISE I.

1. What would be the height of a mountain at the top of which the barometric pressure amounts to 20 inches?

2. What is the height of the column of mercury in the barometer on Mont Blanc (16,000 feet) and Ben Nevis (4,000 feet)?

3. Carrying a barometer and a thermometer, I commence the ascent of a hill. At the base the mercury column stands at 29 inches, at the summit 23 inches. What are the respective heights of the positions, and what the readings of the thermometer for the boiling point of water (1° F. fall for 590 feet)?

4. What is the velocity of sound through air at a temperature of 35° C.?

5. When making an experiment to ascertain the velocity of sound, I found that in a certain state of the atmosphere it was 1,130 feet per second. The centigrade thermometer gave the temperature at 20°. Make the proper allowance for this, and give the result.

6. How much less time is taken up by the journey *of sound* in river water (4,708 feet per second) than *in air* at 10° C., in a distance of 10 miles?

Exercise II.

1. A tuning-fork vibrates 256 times per second, the temperature of the air being at 5° C. What is the length of the wave produced?

2. Length of wave 4 inches; temperature 15° C. What is the number of vibrations?

3. What is the velocity of sound in air which is at a temperature of 50° C.?

4. In a thunderstorm the sound is heard 6 seconds after the flash is seen; temperature of the air 30° C. What is the distance of the electric discharge?

5. The report of a pistol is heard 3 seconds after the flash is seen; temperature of the air 10° C. What is the distance at which the pistol was discharged?

6. Wishing to ascertain the width of an inlet of the sea, a gun was fired on one side, and the observer on the opposite shore noted the flash and sound; the time between them was $10\frac{1}{2}$ seconds. What was the width?

Exercise III.

1. What is the ratio between the numbers of vibrations made by two strings, whose stretching weights are 16 and 25 lbs. respectively?

2. A string, 2 feet long, vibrates 230 times per second; increase the length to 3 feet. What is now the number of vibrations per second?

3. A string, $\frac{1}{4}$ inch in diameter, vibrates 120 times per second. What number of times will it vibrate when the diameter is increased to $\frac{1}{2}$ inch?

4. I represent the densities of two substances by the numbers 16 and 49. If a string of the first material vibrates 450 times in a second, what will be the number of vibrations of a string of the other material?

5. A string, 14 inches long, and stretched by a weight of 4 lbs., vibrates 100 times per second. What will be the length of a string of 16 lbs. tension which vibrates 400 times per second?

Exercise IV.

1. A tube, 9 inches in length, resounds to the vibrations of a tuning-fork. Required the length of the wave, and the number of vibrations; temperature 62° F.

2. The column of air in an organ pipe vibrates 220 times per second. What is the length of tube which resounds to it (1,120 feet per second at 62° F.)?

3. You fire a shot before a cliff, and hear the echo 5 seconds afterwards. What is the cliff's distance from the centre of explosion (1,120 feet per second at 62° F.)?

4. At one end of a Ritchie's photometer I place a candle, at the other end a gas flame. To get equal shadows I place the candle 6 inches away, and the gas flame 3 feet. What are the comparative intensities?

5. If at a distance of 1 foot from a candle I represent the light falling on an object by the number 1, what number must I use to represent the intensity of the light at a distance of 6 feet?

6. At a distance of 6 feet from a burning gas jet I get an amount of light which I will represent by the number 36. What relative number gives the intensity at 2 feet?

Exercise V.

1. The volume of a gas at 0° C. is 50 cubic feet. *What* is the volume at 30° C.?

2. The volume of a gas at 20° F. is 100 c. f.; what will be the increase of volume when the temperature is raised to 75° F.?

3. Express in the centigrade scale the following temperatures of Fahrenheit:—10°, 0°, 180°, 212°.

4. Express in Fahrenheit the temperatures 5° C., 100° C., 15° R., 0° R., 80° R.

5. In Canada the winter temperature sometimes falls 25° F. below zero. Express this in the centigrade and Reaumur scales.

Exercise VI.

1. What is the temperature at which water boils on Snowdon (3,500), Mont Blanc (16,000), and Mount Everest (29,000 feet high)?

2. In ascending a mountain I attempt to cook meat by boiling; the water boils, but the meat is not cooked. I test the water, and find that it is at a temperature of 195° F. What is my perpendicular distance from the level of the sea?

3. If an iron ball weighing 20 lbs. at a temperature of 40° C. fall 772 ft. into 10 lbs. of water, and impart to it all its heat, what will now be the temperature of the water, which before was 5° C.?

4. How much air would be raised 20° F. in temperature by all the heat from 2 cubic feet of water at 20° F.?

5. A pound of iron at a temperature of 100° imparts all its heat to a pound of water at 50°. How many degrees will the temperature of the water be raised (sp. heat of iron 0·1)?

6. The sp. heat of air is 0·25; its sp. gr. is $\frac{1}{770}$, water being unity. A cubic foot of water at 70° F. is placed in contact with 100 cubic feet of air at 50°; the water sinks to 69°. Supposing all the heat that

the water has lost communicated to the air, what would be the rise in temperature of the latter?

Exercise VII.

1. How many degrees of heat C. and F. are required to turn 1 lb. of ice into steam?

2. 5 lbs. of steam are condensed to water, and then frozen. How many pounds of water at 0° C. may be made to boil with the heat given up?

3. An ounce of steam at a temperature of 212° F. is added to a pound of water at 50°. What is the temperature of the mixture?

4. Allow a jet of steam to play into a vessel containing water at 0° C. How much steam will be required to make the water (10 lbs.) boil?

5. Into a vessel containing 20 lbs. of water at 10° C. I immerse 1 lb. of ice; the water will fall in temperature. When the ice is completely melted, what is the temperature of the whole?

6. A thermometer at 20° C. is placed in ice. The ice is heated till it all melts; the water is then heated until it is converted into steam. Give the readings from the thermometer throughout.

Exercise VIII.

1. 1 lb. of iron at 0° C. falls from a height ot 1 mile. What will be its temperature, supposing all the heat generated by the concussion to be imparted to the iron ball?

2. How much water would be raised 1° C. in Example 1 if the ball fell into water and the whole of the heat was imparted to the water?

3. How much ice would be melted by the fall of a 60-lb. ball from a height of 772 yards?

4. A 68-pound cannon ball strikes a target at a

velocity of 1,400 feet a second. Supposing all the heat generated by the collision to be communicated to 68 lbs. of water at 60° F., how many degrees would the temperature of the water be raised?

5. A leaden bullet weighing 1 oz. strikes a target at a velocity of 669 yards per second. What amount of heat will be generated by the stoppage?

6. If 20 lbs. of water be allowed to fall from a height equal to that of Mont Blanc (16,000 ft.), and its motion be arrested, what will be the increase of temperature of the water?

ANSWERS TO PROBLEMS.

EXERCISE I.—(1) 8,000 ft. (2) 10 in., 25 in. (3) 800 ft., 5,600 ft., 210·7° F., 202·5° F. (4) 1,160 ft. per sec. (5) 1,090 ft. per sec. (6) 36·3 sec.

EXERCISE II.—(1) 4·3 ft. (2) 3,360. (3) 1,190 ft. per sec. (4) 2,300 yds. (5) 1,110 yds. (6) 2·2 miles nearly.

EXERCISE III.—(1) As 4 : 5. (2) 153. (3) 60. (4) 257. (5) 7 in.

EXERCISE IV.—(1) 3 ft., 374. (2) 15 in. (3) 2,800 ft. (4) As 36 : 1. (5) $\frac{1}{36}$. (6) 324.

EXERCISE V.—(1) 55·4. (2) 111. (3) −23·3, −17·7, 82·2, 100. (4) 41, 212, 66 nearly, 32, 212. (5) −31·6, −25·3.

EXERCISE VI.—(1) 206° F., 185° F., 163° F. (2) 10,030 ft. (3) 15° C. (4) 6,160 cubic ft. (5) 10°. (6) 30·8.

EXERCISE VII.—(1) 716·6. 1,322. (2) 35·8. (3) 117° F. (4) 30 oz. nearly. (5) 5·7° C. (6) 20° C., 0° C., 100° C.

EXERCISE VIII.—(1) 61·2° C. (2) 6·8 lbs. (3) 2·2 lbs. (4) 36. (5) 81°. (6) 20·7.

GLOSSARY OF TERMS USED IN THE SCIENCE OF ACOUSTICS.

Amplitude.—The distance through which a vibrating body moves in generating a complete wave of sound.

Beats.—When interference proceeds with regularity there is a swell and fall of sound at regular intervals, known amongst musicians by the name of beats.

Clang-tint.—A term used by Professor Tyndall instead of *timbre*, which see.

Condensation.—The act of becoming more dense, and consequently filling less space.

Density.—The relative weight of a given volume of any substance as compared with some standard as unity.

Diatonic Scale.—The natural scale of tones and semitones from C to C^1.

Dissonance.—A disagreeable effect on the ear, caused by a rapid succession of beats.

Echo.—The repetition of a sound by reflection of the sound-wave from rocks, trees, &c.

Elasticity.—The pressure which a body is able to support.

Eustachian Tube.—A passage connecting the middle ear with the mouth.

Foci.—The points where waves of sound meet after reflection and refraction by curved surfaces, and combine to form distinct sounds.

Fundamental Note.—The true note produced when a sonorous body is thrown into vibration; this note

determines the pitch, and upon it the overtones are superposed.

Gamut.—The modern scale of music.

Glottis.—The narrow opening at the top of the windpipe, across which the vocal chords are stretched.

Harmonics.—The notes produced by the vibrations of the aliquot parts of a sonorous body.

Interference.—A term applied to certain effects in acoustics and light, which are caused by one wave overtaking and partially or wholly destroying another.

Isochronal.—Performed in equal times.

Larynx.—A cartilaginous cavity at the top of the windpipe.

Medium.—The body through which a force is transmitted.

Musical Concord.—A combination of tones which is agreeable to the ear, and is produced by waves of sound succeeding each other at exactly equal intervals of time.

Nodal Lines and Points.—Lines and points which are in a state of rest when the other parts of the same body are vibrating.

Rhythm.—A regular succession of impulses at equal intervals of time.

Sinuous.—Winding, undulating.

Stethoscope.—A funnel-shaped instrument of light wood, for increasing the intensity of sound. Used by physicians to detect injured internal organs of the body.

Tension.—Strain, or degree of stretching, which a substance suffers.

Timbre.—The quality of a sound, which enables us to detect the difference between two instruments; as. for example, a flute and violin, when the same note is sounded. It is due to the addition of overtones upon the fundamental tone.

Transversal.—In a direction at right angles to the length.

Tympanum.—The drum of the ear.

Undulation.—A vibratory motion in the form of a wave.

Velocity of Sound.—The rate per second at which sound travels.

Vibrating Segments.—The parts of a medium which are vibrating when the other parts are at rest.

Vibrations.—The motions of a body which result in the production of sound.

Vocal Chords.—A number of elastic bands stretching across the top of the windpipe. Air is forced through these, compelling them to vibrate.

TERMS USED IN THE SCIENCE OF LIGHT.

Aberration, Chromatic.—The primary colours are not equally refrangible, therefore when passing through a lens these colours focus at slightly varying points, so as to give rims of colour around the objects viewed.

Aberration, Spherical.—In mirrors and lenses of greater angular aperture than 10° or 12° the outer rays cross the inner when coming to a focus, and the image is distorted.

Accidental Images.—Images of a complementary colour, seen playing around a coloured object after the eye has been upon it for some time.

Achromatic (without colour).—Lenses that are achromatic have the dispersion neutralized without material injury to refraction.

Actinic Rays.—Those rays in the spectrum which have chemical properties.

Angle of Incidence.—The angle made by the ray falling on a mirror with the normal.

Angle of Reflection.—The angle made by the reflected ray with the normal.

Binocular Vision (two-eyed vision).—Vision by means of two views, right and left handed, which give the appearance of solidity.

Caustics.—The curved lines of light produced by aberration in mirrors or lenses.

Centre of Curvature.—The centre of a spherical surface of which the curve forms a part.

Complementary Colours.—White light is composed of three colours,—blue, red, yellow. This term is applied to the colour or colours absent which, if present, would give white light. Thus, taking red as a colour, its complementary colour is green (blue and yellow).

Convergent.—Coming together, as rays distant from each other coming to a point.

Critical Angle.—The angle at which refraction ceases and total reflection begins.

Daltonism.—A defect of sight by which colours cannot be distinguished from each other.

Diffraction.—Dispersion of light on passing the edge of an opaque screen, or going through a small aperture.

Dispersion.—The spreading out of a ray of white light when passing through a medium whose opposite sides are not parallel, which produces the spectrum colours.

Divergent.—Receding from each other, as lines when leaving a point.

Double Refraction.—The division of a compound ray of light into the ordinary ray and the extraordinary, on entering and passing through crystals.

Extraordinary Ray.—That part of the compound ray which does not obey the ordinary laws of refraction.

Frauenhofer's Lines.—Certain dark lines, first observed by Frauenhofer, crossing the solar spectrum.

Fundamental Colours.—The three colours—blue, red, and yellow—of which white light is composed.

Goniometer.—An instrument for measuring angles by means of rays of light.

Heliostat.—A mirror moved by clockwork apparatus so as to follow the sun's motions. Used for throwing the sun's rays in any required direction.

Homogeneous.—Of the same nature throughout.

Irradiation.—A peculiar alteration, in apparent size, of white objects on a dark ground, or of black objects on a light ground.

Mirage.—A peculiar phenomenon observed at sea and in sandy deserts, by which inverted images of invisible objects are seen.

Monochromatic.—Of one colour throughout.

Myopy.—Short-sightedness.

Newton's Rings.—Coloured rings produced by interference when a slightly convex glass is pressed upon a plane one.

Normal.—A standard or rule from which to calculate. In Optics, perpendicular; at right angles.

Ophthalmoscope.—An instrument for ascertaining the power of the eye.

Optical Centre.—The centre of that part of the principal axis which is in the lens.

Ordinary Ray.—The part of a compound ray which on separation follows the ordinary laws of refraction.

Parabolic.—Having the form of a parabola; as a parabolic curve.

Penumbra (*almost a shadow*).—The partially illuminated surface surrounding a true shadow.

Photometer (*light-measurer*).—An instrument used for ascertaining the relative intensities of different lights.

Polarization.—The division of a compound ray of light into two rays, which are in planes at right angles to each other.

Polarizing Angle.—The angle at which a ray of light must strike or pass through a substance to be completely polarized.

Presbyopy.—Long-sightedness.

Reflection.—The act of being bent back or thrown off on striking an object.

Refraction.—The bending which a ray of light suffers on entering another medium.

Refrangibility.—The property of being refracted.

Secondary Axis.—In Mirrors, a line drawn through the centre of curvature. In Lenses, a line which does not pass through the centre of curvature, but through the optical centre.

Spectroscope.—An instrument for ascertaining the constitution of incandescent substances by observation of the spectra which they produce.

Spectrum.—A dispersed ray of light, showing colours.

Total Reflection.—The effect observed when a ray of light strikes a surface at an angle beyond the critical angle. The whole of the light is reflected.

Virtual Images.—Images which have no real existence. They cannot be obtained on screens, but only exist theoretically, as it were, by an imaginary prolongation of the rays of light.

Virtual Foci.—Foci to which the same remarks apply, substituting "foci" for "images."

Visual Angle.—The angle formed by the outer rays of distinct vision.

TERMS USED IN THE SCIENCE OF HEAT.

Athermancy.—The property of being opaque to the passage of heat rays.

Calorimeter.—An instrument for ascertaining the specific heat of substances.

Co-efficient of Expansion — Linear, Superficial, Cubical. — The number expressing the expansion which a unit of length, surface, or volume undergoes on the application of 1° of heat.

Conduction.—The passage of heat from molecule to molecule without a disarrangement of the particles of which the substance is composed.

Congelation.—The act of congealing or freezing.

Convection.—The act of imparting heat by a motion or transmission of the particles, all in turns coming under the influence of the heat.

Cryophorus.—An instrument for producing ice on abstraction of heat, by means of liquid turning to vapour.

Cubical Expansion, or Expansion of Volume.—The expansion of a solid unit of any substance.

Diathermancy.—The property of being transparent to heat rays.

Differential Thermometer. — A thermometer for showing the comparative temperatures of two bodies.

Dilatation.—The act of dilating or expanding.

Dynamic Heat.—Heat in motion.

Ebullition.—The act of boiling.

Hygrometer.—An instrument for ascertaining the degree of moisture in the atmosphere.

Latent Heat.—The amount of heat absorbed by a

body when changing its state of aggregation, and which is not shown by the thermometer.

Material Theory.—This theory advances the opinion that light and heat are themselves material bodies, and that the phenomena of these sciences are brought about by the action of material particles.

Mechanical Theory. — This theory suggests that light and heat are not in themselves material, but that they act on material bodies by motion imparted and continued.

Periodic Winds.—Those which blow at well-known periods, as the monsoons.

Pyrometer.—An instrument for measuring expansion on the application of heat.

Radiation.—The act of throwing off heat in all directions.

Refrigeration.—The act of cooling.

Regular Winds.—Those which blow all the year round in the same direction.

Specific Heat.—The relative quantity of heat required to raise a body to the same temperature as a given standard.

Superficial Expansion.—Expansion of a unit ot surface.

Thermometer (heat-measurer).—An instrument for ascertaining temperatures.

Variable Winds.—Those which are not constant, but change without any apparent reason.

EXAMINATION QUESTIONS, MAY, 1868.

ACOUSTICS, LIGHT, AND HEAT.

GENERAL INSTRUCTIONS.

YOU may select either the first paper or the second paper, but you must confine yourself entirely to the paper you select.

You are only permitted to attempt eight questions.

These eight questions may be selected from the first paper, or rom the second paper, in the proportion stated at its head, but not from both.

If these rules are not strictly observed, the candidate's paper will be cancelled.

The same value is attached to the correct answer of each question.

Three hours are allowed for this examination.

N.B.—A full and correct answer will in all cases gain more marks than an inexact or incomplete one.

FIRST OR EASY PAPER, FOR 3RD, 4TH, AND 5TH CLASSES.

Eight questions:—two in acoustics, three in light, three in heat.

1. Describe the manner in which sound is propagated through air, water, or wood.
2. How are musical sounds produced? On what do the *pitch* and the *intensity* of a musical sound depend?
3. How many vibrations per second are necessary for the formation of sound-waves three feet in length?
4. How are echoes produced? State all you know regarding the law which regulates the production of echoes.
5. State what you know regarding the structure of the human eye.
6. State what you know regarding the form and use of spectacles.
7. State what you know regarding the production of the

colours of flowers. Why, for example, is a rose red, and grass green?

8. A cloud is composed of transparent water particles; but if transparent, why are clouds able to intercept so much of the sun's light?
9. What is the velocity of light, and how has it been ascertained?
10. By what means do we ascertain that one light has eight or ten, or any other number of times the intensity of another?
11. Explain the construction of the common mercurial thermometer, and state how the thermometers of Fahrenheit and Reaumur, and the centigrade thermometer are graduated.
12. What is meant by the *boiling point* of a liquid? What is the boiling point of water, and how could water be heated above its ordinary boiling point? How is the boiling point affected when we ascend a mountain?
13. I heat a ball of lead and one of iron to the temperature of boiling water. I then place both balls on wax or snow. Will they sink to the same depth? State what you know regarding the subject touched upon in this question.
14. State what you know regarding the radiation of heat from the earth, and the effects produced by this radiation.
15. Give a clear statement of what you understand by the *radiation*, the *reflection*, and the *absorption* of heat.

Second or Difficult Paper, for 1st, 2nd, and 3rd Classes.

Eight questions:—two in acoustics, three in light, three in heat.

16. How is the rate of vibration of a string affected by its length, density, thickness, and tension?
17. Describe the manner in which a bell divides itself when it sounds its fundamental note. What other notes and modes of division are possible to the bell?
18. Describe the manner in which the air vibrates within an organ pipe when it sounds its fundamental note, its first harmonic, and its second harmonic.
19. State what you know regarding the *beats* of musical sounds.
20. Why is it that when you look straight down into trans-

parent water it appears shallower than it really is? Deduce from this apparent lifting of the bottom the manner in which a straight stick is bent when it is thrust obliquely into water.

21. State what you know regarding the lines of Frauenhofer.
22. Explain the construction of the common opera-glass.
23. What is meant by the *dispersion* of light? Can dispersion be neutralized without neutralization of reflection? State what you know regarding achromatism.
24. Describe an experiment which shall illustrate the *spherical aberration* of a lens.
25. Describe an experiment which shall illustrate the *chromatic aberration* of a lens.
26. How are the boiling point of water and the melting point of ice affected by pressure?
27. What is the co-efficient of expansion of atmospheric air? Why is it that the co-efficients of expansion of gases exhibit a much closer agreement than those of liquids and solids?
28. Certain gases deviate from the normal standard in their expansion by heat: state what you know regarding the cause of this deviation, and the circumstances under which it is observed to occur.
29. State fully the atmospheric conditions favourable to the copious deposition of dew. Describe the influence of clouds and winds upon this phenomenon.
30. State what you know regarding the absorption of radiant heat by solids, liquids, and gases. Explain in accordance with the mechanical theory of heat what is meant by radiation and absorption.

EXAMINATION QUESTIONS, MAY, 1869.

ACOUSTICS, LIGHT, AND HEAT.

First Stage, or Elementary Examination.

INSTRUCTIONS.

Eight questions are to be attempted:—two in acoustics, three in light, three in heat.

In all cases the number of the question must be placed before the answer on the worked paper.

Three hours are allowed for this paper.

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1. The velocity of sound in water is much greater than its velocity in air; why is this the case?
2. You are required to express numerically the elasticity of the air on the top of a mountain as high as Mont Blanc, on the top of a mountain as high as Ben Nevis, and at the sea level; how will you do it?
3. A tuning-fork vibrates 512 times a second; what is the length of the sonorous wave which it would produce in an atmosphere of hydrogen, supposing the velocity of sound in hydrogen to be 4,200 feet a second?
4. Why should a lake, the bottom of which you can see, appear shallower than it really is?
5. I wish you to compare the light of a candle flame with that of a gas flame of the same size. How will you determine and express numerically the relative intensities of the two lights?
6. A large concave mirror is placed before you. You see your image first inverted in the air; you change your distance from the mirror, and find that in a certain position your image vanishes; again you change your position and find your image erect. Under what circumstances are these effects observed? State whether the images observed are of greater or less size than yourself, and give the reason of the increase or diminution.
7. Describe and explain the camera obscura.
8. Describe the circumstances under which total reflection takes place. Supposing your eyes were placed under the water of a lake, what appearance do you suppose a man standing on the brink of the lake would present to you?
9. How are the volumes of bodies affected by heat? State such exceptions to the general rule as may be known to you.
10. I place water, alcohol, and ether, all of the same temperature, on my hand in succession. I experience a certain cold from the water, a greater cold from the alcohol, and a still greater cold from the ether. State what you know regarding the cause of these differences.
11. A pound of iron at a temperature of 100° is immersed in a pound of water at a temperature of 50°; how many degrees

will the temperature of the water be exalted? Note:—The specific heat of iron is 0·1.

12. A plate of rock-salt if placed in front of a fire will not be heated, while a plate of glass will be heated. A hot plate of rock-salt held at a short distance from the face hardly warms the face, while a hot plate of glass does warm it. Explain these effects.

Second Stage, or Advanced Examination.

INSTRUCTIONS.

Eight questions are to be attempted:—two in acoustics, three in light, three in heat.

In all cases the letter distinguishing the question must be placed before the answer on the worked paper.

Three hours are allowed for this paper.

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a. The rapidity with which sound passes through air at an elevation equal to that of the summit of Mont Blanc is less than its rapidity at the sea level; explain the cause, and state generally the conditions which influence the velocity of sound in air and other bodies.

b. Supposing the velocity of sound to augment two feet per second for every degree centigrade of temperature above the freezing point, what would be the temperature of air in which the velocity of sound is 1,500 feet a second? What would be the length of the waves excited by a tuning-fork vibrating 512 times a second in such air?

c. Two tuning-forks of the same temperature vibrate at the same rate; I heat one of them, and thus lower a little its rate of vibration. What effect will now be produced when the forks are sounded together? Explain why the effect observed should be produced.

d. Describe and explain some one form of the reflecting telescope.

e. Describe some one form of the refracting telescope.

f. I possess a liquid the colour of which is neither red nor blue, but a mixture of both, or purple. I decompose a beam of light and produce a spectrum. What effect will the liquid have upon the spectrum when it is placed in the path of the decomposed beam?

g. A beam of light impinges as a perpendicular on one of the sides of a right-angled prism. It enters the prism and meets the hypothenuse. Prove that it will be there totally reflected.

h. The air of a glass house into which the solar rays enter may be warmed by those rays to a much greater degree than the air outside the house; what do you suppose to be the cause of this? Apply your knowledge to explain the influence of the earth's atmosphere upon the temperature of the earth.

i. An ounce of steam at a temperature of 212° Fahr. is added to a pound of water at a temperature of 50°; what will be the temperature of the mixture?

j. The specific heat of air is 0·25; its specific gravity is $\frac{1}{770}$, water being unity. A cubic foot of water at 70° Fahr. is placed in contact with 100 cubic feet of air at 50°; the water sinks to 69°; supposing all the heat that the water has lost communicated to the air, what would be the exaltation of the temperature of the air?

k. Sketch the gridiron pendulum, and state fully the principle on which its construction depends.

l. A 68-pound cannon ball strikes a target at a velocity of 1,400 feet a second. Supposing all the heat generated by the collision to be communicated to 68 lbs. of water at 60° Fahr., how many degrees would the temperature of the water be raised?

Honours Examination.

Candidates are permitted to attempt all the questions.

In all cases the letter distinguishing the question must be placed before the answer on the worked paper.

Three hours are allowed for this paper.

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p. Describe the relation which subsists between the radiation and the absorption both of light and radiant heat. Apply your knowledge to the explanation of the dark lines on the solar spectrum.

q. What is the condition of a tuning-fork as regards its nodes and ventral segments when it sounds its fundamental note?

How has the division of a tuning-fork by nodes been determined? In what order do the higher rates of vibration of a tuning-fork follow each other?

r. From the ratio of the specific heat of air at constant pressure to its specific heat at constant volume you are required to deduce the mechanical equivalent of heat. How will you do it?

s. Sketch an experimental arrangement by which you would illustrate to a class the absorption of radiant heat by glass and its transmission by rock-salt.

t. The dark powder of iodine absorbs the radiant heat of a fire much less copiously than the white powder of alum. Explain the effect. Describe the character of the rays emitted by the sun throughout the entire range of the spectrum, visible and invisible.

NOTE.—In addition to these questions the candidate may select any that he pleases from the other two papers.

EXAMINATION QUESTIONS, MAY, 1870.

ACOUSTICS, LIGHT, AND HEAT.

GENERAL INSTRUCTIONS.

You are only permitted to answer questions from the elementary paper or from the advanced paper, but not from both. If the rules are not attended to, the paper will be cancelled.

In all cases the number of the question must be placed before the answer on the worked paper.

Three hours are allowed.

First Stage, or Elementary Education.

INSTRUCTIONS.

You are only permitted to attempt *eight* questions. You may only select *two* in acoustics, *three* in light, and *three* in heat.

The value attached to each question is the same.

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1. You fire a shot before a cliff, and hear the echo five seconds afterwards. What is the cliff's distance from the centre of explosion?
2. How do you suppose the human voice to be produced?

3. What occurs in the case of your voice when you sing high notes and low notes? I mean, what is the condition of the vocal organ when the two kinds of notes are sounded?
4. Air and hydrogen gas are urged in succession through the same organ pipe. Describe the effects and explain them.
5. What is meant by the scattering of light, and what by its regular reflection?
6. Give some proof that light itself is invisible.
7. There is a lake in Ireland called the Lake of Shadows, because the images of the clouds are frequently seen in the lake. Are these images really shadows? If not, what are they? Describe their formation.
8. I fill two cups of the same depth with two different liquids, and notice two things: firstly, both cups appear shallower than when they were empty; and secondly, one of them appears shallower than the other. Explain the observation.
9. Describe clearly an experiment by which white light can be resolved into the differently coloured lights which compose the white. Describe also an experiment by which the colours can be re-compounded.
10. How is the heat of a fire produced? How is the heat of your own body produced?
11. Are clothes really warm? If not, why are they sometimes called warm? What is the real meaning and action of cool dresses and warm dresses?
12. State what you know about the act of boiling and the act of freezing.
13. Express, in the centigrade scale, the following temperatures of Fahrenheit:—10°, 0°, 180°, and 212°.
14. Explain the formation of dew and hoar-frost.

Second Stage, or Advanced Examination.

You are only permitted to attempt *eight* questions. You may only select *two* in acoustics, *three* in light, and *three* in heat.

The value attached to each question is the same.

Read the general instructions at the head of the Elementary Paper.

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20. What is meant by the amplitude of a vibrating particle? and by what law is the loudness of sound connected with amplitude?

21. Describe the syren of Caignaird de la Tour.
22. A jar containing air, and another containing hydrogen, resound to the same tuning-fork. Are the jars alike? If not, state and explain the difference between the two jars.
23. What is the cause of consonance and of dissonance in music?
24. Very little light is absorbed by a layer of clear water a foot in depth; still, the water may be powerfully heated by the sun's rays. Whence comes this heat?
25. Draw a diagram to show the positions the eye of a spectator must occupy to see a partial, total, and annular eclipse of the sun.
26. Describe and explain Bunsen's photometer.
27. When an image is formed by a concave mirror, in certain positions you see the image in the air, while in certain other positions you do not see it. If, however, a sheet of tracing-paper receive the image, it is seen from positions, before and behind, in which the aërial image was invisible. Explain all this.
28. Describe some experimental mode of determining the index of refraction of a transparent liquid.
29. There are two theories of Light—the theory of Undulation and the theory of Emission. Describe them both, and state what is known to you that renders one of them preferable to the other.
30. How is the temperature of the air affected by the passage of sound through it?
31. What is the meaning of specific heat at constant volume, and specific heat at constant pressure? What is the ratio of the one to the other?
32. A black hat is more heated by the solar rays than a white one: what is the reason? Dark iodine is, however, less heated by the same rays than white sugar: what is the reason?
33. State and illustrate what is meant by Athermancy and Diathermancy. Describe the thermo-electric pile.

Honours Examination.

INSTRUCTIONS.

The value attached to each question is the same.

40. What is meant by Laplace's correction for the velocity of sound in air? Give a clear statement of the nature and amount of the correction.

41. Describe and explain Hadley's sextant.
42. Deduce the mechanical equivalent of heat from data furnished by the velocity of sound in air.
43. Describe and explain the lines of Frauenhofer, and deduce from them a theory of the composition and constitution of the sun.
44. Between two crossed Nicol's prisms you introduce a plate of selenite, and find that the field which was previously dark is now bright. Explain the effect. In what position of the selenite is the transmitted light a maximum?
45. Explain the colours of a plate of selenite in polarized light.

INDEX.

THE END.

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